UNIVERSITY OF CALIFORNIA
COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
BERKELEY, CALIFORNIA

MEASURING WATER FOR IRRIGATION

J. E. CHRISTIANSEN

BULLETIN 588
MARCH, 1935

UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA

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MEASURING WATER FOR IRRIGATION[1]

J. E. CHRISTIANSEN[2]

THE CHIEF PURPOSE of this bulletin is to describe the more common methods and devices used in measuring water for irrigation in California. Although it has been prepared primarily to meet the needs of farmers, ditch-tenders, and county agents, experience has shown that a compendium of practical information on this subject may be advantageously expanded to include an explanation of some principles of water measurement and a discussion of some methods with which farmers, ditch-tenders, and county agents ordinarily are not concerned, but which will interest students and engineers.

The more practical aspects of water measurement, together with tables for use with important devices, are presented in the first part of this bulletin. Explanations of theory and discussions of methods not ordinarily used in measuring water for farmers appear in the second part.

COMMON METHODS AND DEVICES USED IN MEASURING WATER FOR IRRIGATION[3]

MEASURING WATER usually means measuring the flow—that is, the volume passing in a unit of time. The flow of a stream in cubic feet per second equals the cross-sectional area, in square feet, at a given section, multiplied by the average velocity, in feet per second, at that section.

Although the flow of rivers and large canals is generally determined from direct measurements of cross-sectional area and velocity, this method is not entirely suitable for small streams. Structures and devices that control the velocity, or the cross-sectional area, or both, are better adapted for this purpose. With them, the flow can be measured more economically and accurately.

The devices and methods most commonly used in California in measuring water for irrigation, particularly in the small streams with which the farmer is chiefly concerned, are: weirs; orifices, including adjustable and fixed-dimension submerged orifices and miner's inch boxes; Parshall measuring flumes; commercial irrigation meters; and miscellaneous methods, including volumetric measurements and the use of current meters or floats.

[1] Received for publication August 13, 1934.

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[3] This part of the bulletin supersedes Bulletin 247, *Some Measuring Devices Used in the Delivery of Irrigation Water,* by California Agents of Irrigation Investigations, Office of Experiment Stations, United States Department of Agriculture; and Circular 250, *Measurement of Irrigation Water on the Farm,* by H. A. Wadsworth.

UNITS OF WATER MEASUREMENT

Two kinds of units are used in the measurement of water: units of volume and units of flow. As previously stated, flow is defined as a rate—the volume that passes a given reference point in a unit of time. The words *flow* and *discharge* are used synonymously.

Units of Volume.—The units of volume commonly used are cubic foot (cu. ft.), gallon (gal.), acre-foot (ac.-ft.), and acre-inch (ac.-in.). An acre-inch is the volume necessary to cover 1 acre to a depth of 1 inch; an acre-foot, to a depth of 1 foot.

Units of Flow.—The common units of flow in irrigation practice are cubic foot per second (cu. ft. per sec. or c.f.s.), gallon per minute (g.p.m.), and miner's inch or "inch" (mi. in.). Less commonly used are million gallons per day (m.g.d.), acre-inch per (24-hour) day, and acre-foot per (24-hour) day.

The cubic foot per second, sometimes written second-foot (sec. ft. or s.f.) or cusec., is the generally accepted standard unit of flow in the English system. Other units are sometimes defined in equivalents of it.

The gallon per minute is commonly used for expressing flow from pumps and wells.

There are two generally accepted miner's-inch units in California. A miner's inch may be defined as the flow through an orifice with an area of 1 square inch under a head which varies locally but which is usually either 4 or 6 inches. The head is the vertical distance from the upstream water surface to the center of the orifice when the downstream water level is below the bottom edge of the orifice—that is, when the orifice is free-flowing.

The California "statute inch," defined as the flow of 1½ cubic feet per minute ($\frac{1}{40}$ cubic foot per second), is the approximate flow through an orifice with an area of 1 square inch under a head of 6 inches. It is used chiefly in the foothills of Sacramento Valley. This same unit is the statute inch in Arizona, Nevada, and Montana.

The "southern California inch" is the flow through an orifice with an area of 1 square inch under a head of 4 inches—approximately $\frac{1}{50}$ cubic foot per second. It is commonly used in southern California and is the statute inch in Idaho, New Mexico, Oregon, Utah, and Washington.

In Colorado the inch is generally assumed to be 1/38.4 cubic foot per second; in British Columbia, 0.028 cubic foot per second. Being so ambiguous, the miner's inch is not a satisfactory unit of flow and in many sections is gradually losing favor. In using it, one should state the head under which it is measured, or its equivalent in cubic feet per second.

The million gallons per day is used principally in connection with municipal water supplies and only occasionally in irrigation. The acre-inch per day and acre-foot per day are sometimes employed.

List of Equivalents.—The following equivalents may be used for converting from one unit to another and in computing volumes from flow units:

1. One cubic foot per second
   - = 448.83 (approximately 450) gallons per minute
   - = 50 southern California miner's inches
   - = 40 California statute miner's inches
   - = 38.4 Colorado inches
   - = 1 acre-inch in 1 hour and 30 seconds (approximately 1 hour), or 0.992 (approximately 1) acre-inch per hour
   - = 1 acre-foot in 12 hours and 6 minutes (approximately 12 hours), or 1.984 (approximately 2) acre-feet per day (24 hours)

2. One gallon per minute
   - = 0.00223 (approximately $\frac{1}{450}$) cubic foot per second
   - = 0.1114 (approximately $\frac{1}{9}$) southern California miner's inch
   - = 0.0891 (approximately $\frac{1}{11}$) California statute miner's inch
   - = 1 acre-inch in 452.6 (approximately 450) hours, or 0.00221 acre-inch per hour
   - = 1 acre-foot in 226.3 days, or 0.00442 acre-foot per day

3. Million gallons per day
   - = 1.547 cubic feet per second
   - = 694.4 gallons per minute
   - = 77.36 southern California miner's inches
   - = 61.89 California statute miner's inches
   - = 1 acre-inch in 39.1 minutes, or 36.84 acre-inches per day
   - = 1 acre-foot in 7 hours and 49 minutes, or 3.07 acre-feet per day

4. One southern California miner's inch
   - = 0.02 ($\frac{1}{50}$) cubic foot per second
   - = 8.98 (approximately 9) gallons per minute
   - = 0.80 ($\frac{4}{5}$) California statute miner's inch
   - = 1 acre-inch in 50 hours and 25 minutes, or 0.0198 (approximately $\frac{1}{50}$) acre-inch per hour
   - = 1 acre-foot in 605 hours (approximately 25 days), or 0.0397 (approximately $\frac{1}{25}$) acre-foot per day

5. One California statute miner's inch
   - = 0.025 ($\frac{1}{40}$) cubic foot per second
   - = 11.22 (approximately 11$\frac{1}{4}$) gallons per minute
   - = 1.25 southern California miner's inches
   - = 1 acre-inch in 40 hours and 20 minutes, or 0.0248 (approximately $\frac{1}{40}$) acre-inch per hour
   - = 1 acre-foot in 484 hours (approximately 20 days), or 0.0496 acre-foot (approximately $\frac{1}{20}$) per day

6. One acre-inch
   = 3,630 cubic feet
   = 27,154 gallons
   = 1/12 acre-foot
7. One acre-foot
   = 43,560 cubic feet
   = 325,851 gallons
   = 12 acre-inches
8. One cubic foot
   = 1,728 cubic inches
   = 7.48 (approximately 7.5) gallons
   weighs approximately 62.4 pounds
   (62.5 for ordinary calculations)
9. One gallon
   = 231 cubic inches
   = 0.13368 cubic foot
   weighs approximately 8.33 pounds
10. One acre
   = 43,560 square feet
   = 4,840 square yards
   = 160 square rods
   is equivalent to a square approximately 209 feet on each side.
11. One rod
   = 16.5 feet
   = 5.5 yards

TABLE 1

CONVERSION TABLE FOR UNITS OF FLOW*

Cubic feet per second	Gallons per minute	Million gallons per day	Southern California miner's inches	California statute miner's inches	Acre-inches per 24 hours	Acre-feet per 24 hours
1.0	448.8	0.646	50.0	40.0	23.80	1.984
0.00223	**1.0**	0.00144	0.1114	0.0891	0.053	0.00442
1.547	694.4	**1.0**	77.36	61.89	36.84	3.07
0.020	8.98	0.0129	**1.0**	0.80	0.476	0.0397
0.025	11.22	0.0162	1.25	**1.0**	0.595	0.0496
0.042	18.86	0.0271	2.10	1.68	**1.0**	0.0833
0.504	226.3	0.3259	25.21	20.17	12.0	**1.0**

* Equivalent values are given in the same horizontal line.

A summary of flow equivalents appears in table 1.

The following approximate formulas may be conveniently used to compute the depth of water applied to a field:

$$\frac{\text{Cu. ft. per sec.} \times \text{hours}}{\text{Acres}} = \text{acre-inches per acre, or average depth in inches.}$$

$$\frac{\text{Gal. per min.} \times \text{hours}}{450 \times \text{acres}} = \text{acre-inches per acre, or average depth in inches.}$$

$$\frac{\text{Southern California miner's inches} \times \text{hours}}{50 \times \text{acres}} = \text{acre-inches per acre, or average depth in inches.}$$

$$\frac{\text{California statute miner's inches} \times \text{hours}}{40 \times \text{acres}} = \text{acre-inches per acre, or average depth in inches.}$$

VOLUMETRIC MEASUREMENTS

Direct volumetric measurements of stream flow can sometimes be made when the stream is discharging into a basin or reservoir of sufficient capacity, as is often the case with farm reservoirs supplied by pumping plants. The volume can be calculated from direct measurements with a tape. The flow is determined by noting the time for the reservoir to fill to a certain depth, or for the water surface to rise from one level to another. The leakage, if appreciable, can be estimated from the time required for the water surface to drop between the same levels when there is no inflow. The reliability of such measurements depends primarily upon the accuracy of determining the volume.

Volumetric measurements are generally employed in hydraulic laboratories for calibrating other devices and instruments used for measuring flow. Weight measurements sometimes serve the same purpose.

STREAM MEASUREMENT BY VELOCITY-AREA METHODS

The flow of a stream can be directly determined by measuring the velocity and the cross-sectional area. The velocity is generally measured with a current meter, although other means, including floats, are sometimes used.

Current Meters.—A current meter is a small instrument containing a revolving wheel or vane that is turned by the movement of the water. Of the several types available, the two most common in California are the Price meter and the Hoff meter (fig. 1).

The Price current meter contains an impeller which consists of six conical-shaped cups mounted on a vertical axis. When the meter is immersed in moving water, the impeller revolves, and the time for a given number of revolutions is determined by the operator. Either every revolution or every fifth revolution is indicated by an electrical sounding device.

The Hoff meter contains a rubber impeller mounted on a horizontal axis. The chief advantage claimed for this type is that it is less affected by eddies or by vertical movement through the water. It has proved satisfactory for measuring the velocity of water flowing from the end of the discharge pipe of pumping plants.

Before being used, current meters are rated or calibrated to determine the relation between the speed of rotation of the impeller and the velocity of the water. From this rating is prepared a graph or table showing the velocity for a given number of revolutions in any time interval.

Current meters are either mounted on a rod, as shown in figure 1, or suspended on a cable above a heavy weight. Rod mountings are used

only in measuring shallow streams. For deep streams or for measurements from a bridge or cableway some distance above the water surface, the cable suspension is used.

Current-Meter Measurements.—Since current-meter measurements are generally made by trained hydrographers or by engineers familiar with this work, only a brief discussion follows.

Current-meter measurements on canals and irrigation ditches are generally made at metering bridges, at cableways, or at other structures giving convenient access to the stream. In shallow streams, measurements are sometimes made by wading. The channel at the measuring section should be straight, with a fairly regular cross section. Structures with piers in the channel are to be avoided when possible.

A *B*

Fig. 1.—Current meters, rod mountings. *A*, Price current meter; *B*, Hoff current meter. Both are interchangeable for rod mounting and cable suspension.

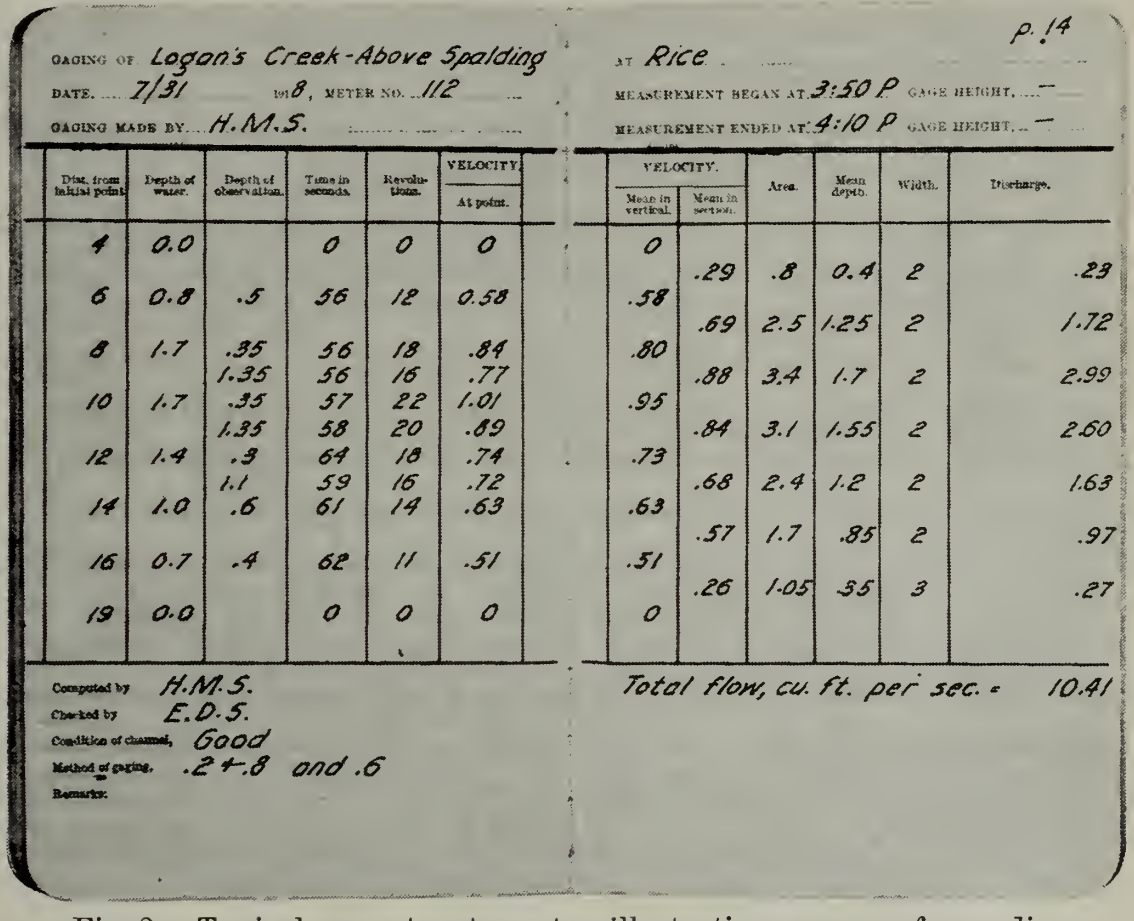
Several measuring points are laid off across the stream at right angles to the direction of flow. These are generally spaced an equal distance apart, not more than the mean depth of the channel nor more than 10 per cent of its width, making a total of not less than ten. At extreme edges additional points are desirable. On large streams a minimum of twenty is ordinarily used.

The depth and mean velocity of the stream in the vertical are determined at each measuring point. When the current meter is mounted on a rod, the depth is measured directly on the rod at the time the velocity is ascertained. When a cable suspension is used, the depth is determined by first lowering the meter to the bottom of the channel, then raising it until it just touches the water surface, and measuring the distance along the cable. When current-meter measurements are made in a rating flume or other channel with regular cross section and level bottom, a gage may be used to indicate the depth of the water. For greater accuracy, the depth is sometimes determined with an engineer's level and rod.

Methods of Determining the Mean Velocity in the Vertical With a Current Meter.—Four methods are used for determining the mean ve-

locity in the vertical with a current meter: multiple-point, two-point, single-point, and vertical integration.

The multiple-point, being the most accurate, is the method by which the accuracy of other methods is generally checked. At each measuring point the velocity is determined at several closely spaced points from the bottom of the channel to the water surface. If these are equally spaced, the mean velocity in the vertical approximates the average of the meas-



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GAGING OF Logan's Creek-Above Spalding AT Rice

DATE. 7/31 1918, METER NO. 112

GAGING MADE BY H.M.S.

MEASUREMENT BEGAN AT 3:50 P GAGE HEIGHT, —

MEASUREMENT ENDED AT 4:10 P GAGE HEIGHT, —

Dist. from initial point	Depth of water	Depth of observation	Time in seconds	Revolutions	VELOCITY: At point	VELOCITY: Mean in vertical	VELOCITY: Mean in section	Area	Mean depth	Width	Discharge
4	0.0		0	0	0	0					
							.29	.8	0.4	2	.23
6	0.8	.5	56	12	0.58	.58					
							.69	2.5	1.25	2	1.72
8	1.7	.35	56	18	.84	.80					
		1.35	56	16	.77		.88	3.4	1.7	2	2.99
10	1.7	.35	57	22	1.01	.95					
		1.35	58	20	.89		.84	3.1	1.55	2	2.60
12	1.4	.3	64	18	.74	.73					
		1.1	59	16	.72		.68	2.4	1.2	2	1.63
14	1.0	.6	61	14	.63	.63					
							.57	1.7	.85	2	.97
16	0.7	.4	62	11	.51	.51					
							.26	1.05	.55	3	.27
19	0.0		0	0	0	0					

Computed by H.M.S.
Checked by E.D.S.
Condition of channel, Good
Method of gaging, .2+.8 and .6
Remarks:

Total flow, cu. ft. per sec. = 10.41

Fig. 2.—Typical current-meter notes, illustrating manner of recording the measurement of a small stream.

ured velocities. This method is seldom used in irrigation practice because of the time required.

In the two-point method, the velocity is determined at two points in the vertical section, their average approximating the mean. The average of the velocities at 0.2 and 0.8 of the depth approximates the mean velocity for ordinary conditions. This method is used extensively by the United States Geological Survey.

In the single-point method, the velocity is determined at a point where it approximates the mean, which generally occurs between 0.5 and 0.7 of the depth below the surface. The velocity at 0.6 of the depth is ordinarily used, although the results are often slightly high. This method is generally employed when the depth is insufficient for the two-point method.

Current-Meter Notes and Method of Computing the Flow.—Typical current-meter notes illustrating the method of recording the data and computing the flow are shown in figure 2. For each vertical strip between two measuring points, the area is taken as the product of the average depth and width; the mean velocity as the average of the mean velocities in the two vertical sections; and the flow as the product of the area and mean velocity. The total flow is the sum of the flows in the vertical strips.

Float Measurements.—Float measurements are ordinarily less accurate than current-meter measurements, except for very low velocities, and are seldom made when other facilities are available. They are comparatively easy and, when care is exercised, fairly accurate.

There are several methods of making float measurements. When accuracy is not essential, the following procedure is fairly simple: A straight course along the stream from 50 to 200 feet in length is selected where convenient access to the stream can be had at the upper end of the course and preferably also at the lower end and intermediate points. At each end of the course a tape or cord is stretched across the stream; and the time required for floats to pass over the course is determined with a stop watch if one is available. Several trials should be made, starting the floats at different positions in the stream channel. A lemon makes a good surface float, although any small object that floats mostly submerged may be used. The velocity of the water is not uniform, ordinarily being greatest below the surface near the middle of the stream. When surface floats are used, the average velocity determined from a number of trials is multiplied by a coefficient to obtain the mean velocity. Experiments have shown that this coefficient varies from 0.55 to nearly 1.0. A value of 0.85 is ordinarily used. That is, the actual flow is only about 85 per cent of that obtained by multiplying the average cross-sectional area of the stream by the velocity indicated by surface floats.

If the channel is of fairly uniform depth, greater accuracy can be secured by using depth or rod floats so weighted that the lower end remains near the bottom of the channel. Such floats will give the approximate average velocity along the line of travel, which may be determined approximately by means of a tape stretched across the channel midway along the course.

The average cross-sectional area is calculated from a number of measurements along the course. These are conveniently taken by measuring the depth at equal intervals across the stream. The average depth thus determined, multiplied by the surface width, will give the approximate area. The average area in square feet multiplied by the mean velocity in feet per second will give the flow in cubic feet per second.

WEIRS

The weir is one of the simplest and most accurate means of measuring the flow of water when conditions are favorable. It may be broadly defined as an overpour obstruction or bulkhead placed across the stream. In this bulletin the term *weir* will be restricted to sharp-crested measuring weirs of standard types, the most common being rectangular contracted weirs, Cipolletti weirs, 90-degree triangular-notch weirs, all shown in figure 3, and rectangular suppressed weirs. Contracted weirs are those producing side contractions in the nappe, or overfalling sheet of water, downstream from the weir crest. To produce this contraction, the crest length, or width of notch, must be less than the channel width.

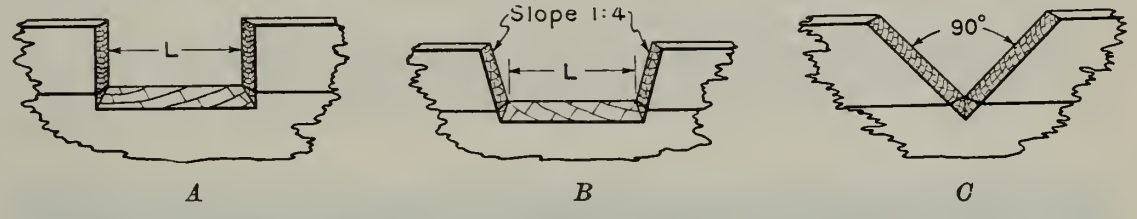


Fig. 3.—Downstream side of contracted weir notches: *A*, rectangular; *B*, trapezoidal or Cipolletti; *C*, 90-degree triangular or V-notch.

On suppressed weirs the crest extends across the full width of the channel, and no contractions are produced. Suppressed weirs, being less common, are discussed in the second part of this bulletin.

Rectangular Contracted Weirs.—The rectangular contracted weir takes its name from the shape of the notch (fig. 3*A*). It is one of the earliest forms used, and from it all others have been developed. Because of its simplicity, easy construction, and accuracy when properly used, it is still the most popular weir.

Cipolletti Weirs.—The Cipolletti weir is a contracted trapezoidal weir in which the sides of the notch slope one horizontal to four vertical (fig. 3*B*). It is named for Cesare Cipolletti, an Italian engineer. Its popularity rests largely upon the belief that the side slopes of one to four are just sufficient to correct for the side contractions of the nappe and that the flow is therefore proportional to the length of the weir crest. Experiments by Cone[4] for the United States Department of Agriculture have shown that this relation does not hold exactly, and that the flow through rectangular notches is more nearly proportional to the length of the crest than through Cipolletti notches. Accurate measurements can be made, however, with this weir if table 5, based on Cone's formula, is used. Being more difficult to construct and having no practical advantages over the rectangular weir, the Cipolletti weir is not recommended.

[4] Cone, Victor M. Flow through weir notches with thin edges and full contractions. Jour. Agr. Research 5(23):1051–1113. 1916.

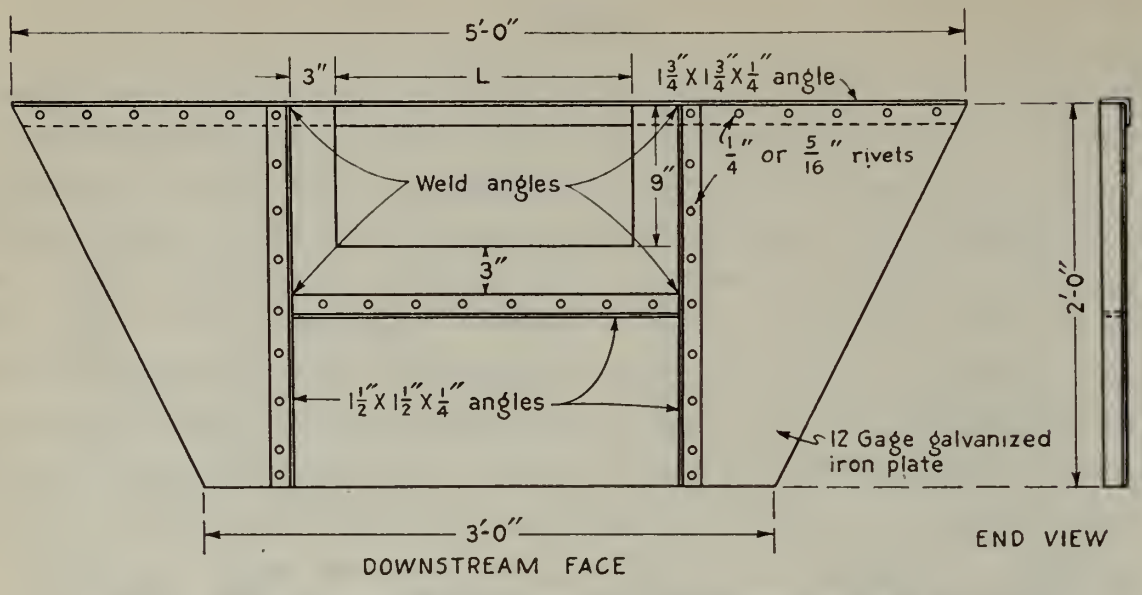


Fig. 4.—Downstream face of portable metal weir suitable for weir notches not exceeding 2 feet crest length.

Fig. 5.—Portable metal weir in use measuring flow of farm ditch. Note hook gage for measuring head.

Ninety-Degree Triangular-Notch Weirs.—The 90-degree triangular or V-notch weir (fig. 3*C*) has a greater practical range of capacity than any other type of a given size. Since, however, it requires a greater loss of head, it is better adapted to measuring flows not exceeding 4 cubic feet per second. Its shape makes it easy to construct and install with the aid of a carpenter's square and level.

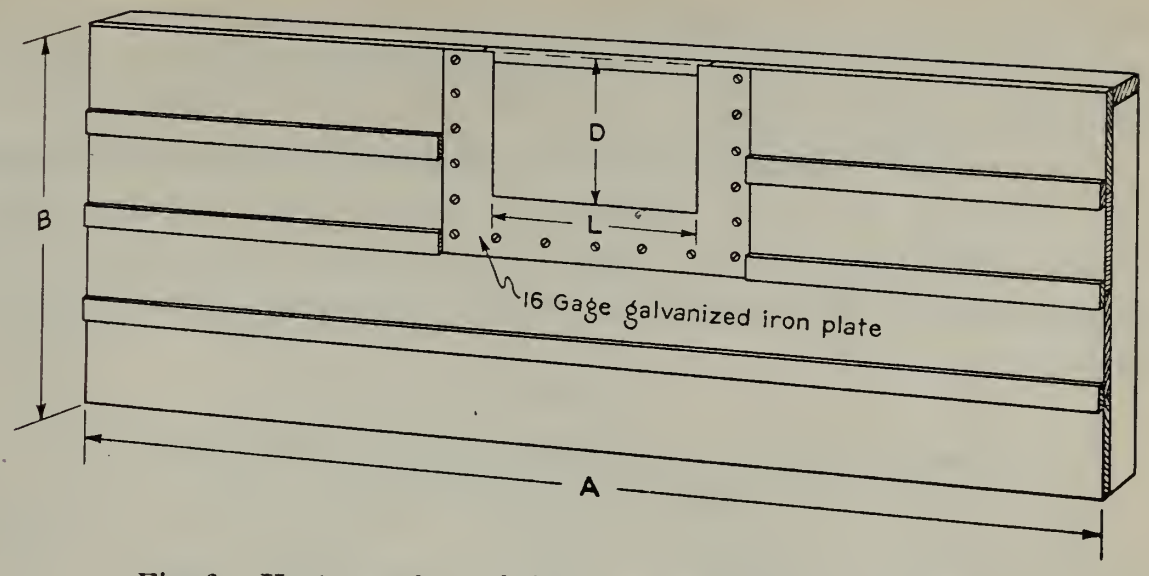


Fig. 6.—Upstream face of single-wall wooden weir structure, especially suitable in heavy soils.

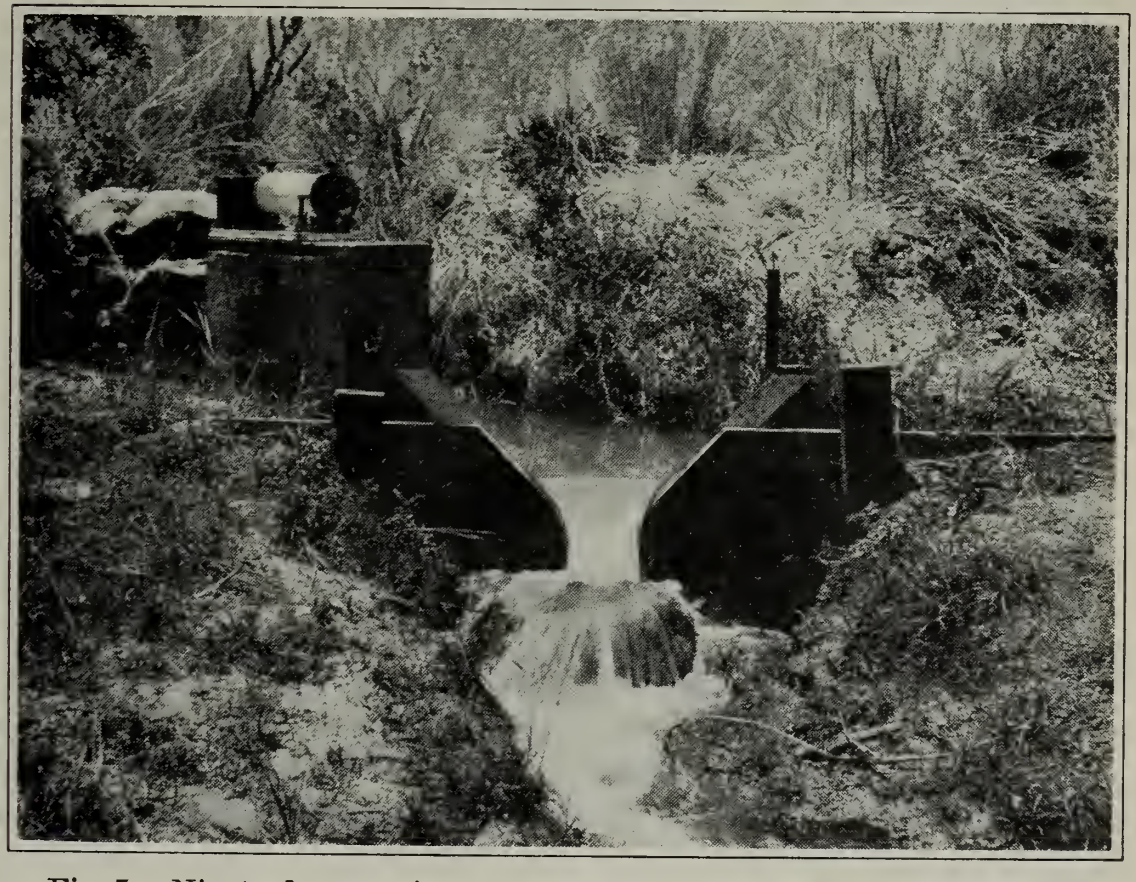


Fig. 7.—Ninety-degree triangular-notch weir; a water-level recorder is being used to obtain continuous record of flow.

The Weir Structure.—The weir structure may be either portable or stationary. Metal weirs are more satisfactory than wooden weirs for portable use. A very substantial metal weir with rectangular notch (fig. 4) is made of ⅛ inch (12 gage) galvanized iron and is stiffened by means of heavy angles, welded together and riveted to the downstream side of the plate with ¼ or 5/16-inch steel rivets spaced not more than 4

inches apart. It can be pounded into position in a flowing stream, with a heavy wooden block or mallet, without shutting off the water. Figure 5 shows a metal weir in use.

A less expensive portable metal weir can be made from a piece of steel plate about ⅛ inch thick, stiffened at the top with two 1 × 4-inch wooden strips bolted to the plate. Two vertical strips bolted to the downstream side, one on each side of the weir notch, will also help to stiffen it.

TABLE 2

RECOMMENDED SIZES AND DIMENSIONS OF WOODEN WEIR STRUCTURES AS SHOWN IN FIGURES 6, 7, AND 8

Approximate range in capacity, cubic feet per second	*L*,* Length of weir crest	*D*, Depth of weir notch	*A*, Length of bulkhead	*B*, Height of structure	*E*,† Length of side walls	*W*,† Outside width of box below weir notch	*C*,† Length of downstream wingwall
For rectangular and Cipolletti weirs							
0.3 to 1.5	1′ 0″	1′ 0″	8′ 0″	3′ 0″	2′ 6″	2′ 0″	1′ 6″
0.5 to 3.0	1′ 6″	1′ 3″	9′ 0″	3′ 6″	3′ 0″	3′ 0″	2′ 0″
0.6 to 6.0	2′ 0″	1′ 6″	10′ 0″	4′ 0″	3′ 0″	3′ 6″	2′ 0″
1.0 to 10.0	3′ 0″	1′ 9″	12′ 0″	4′ 6″	3′ 6″	5′ 0″	2′ 6″
1.5 to 20.0	4′ 0″	2′ 0″	14′ 0″	5′ 0″	4′ 0″	6′ 0″	3′ 0″
For 90-degree triangular notch weirs							
0.02 to 1.5	2′ 0″	1′ 0″	8′ 0″	3′ 0″	2′ 6″	3′ 0″	1′ 6″
0.02 to 4.0	3′ 0″	1′ 6″	9′ 0″	3′ 6″	3′ 0″	3′ 6″	2′ 0″

* For 90-degree triangular weirs, *L* indicates top width of notch.
† Applies to figure 8 only.

The dimensions for portable weirs given in figure 4 are approximately right for flows not exceeding 2½ cubic feet per second.

Wooden weirs, though suitable as stationary structures, are less convenient for portable use. Simple types, as shown in figures 6 and 7, are inexpensive and, if made of heart redwood, fairly durable. The ditch in which one is installed should be protected for a short distance downstream to prevent the overflowing water from washing a hole and undermining the structure. Cobblestone rip-rap, a wide board placed crosswise about 4 inches below the bottom of the ditch, or a piece of canvas or burlap fastened to the downstream side will usually suffice. The recommended sizes and dimensions for such weirs are given in table 2.

The type of structure shown in figure 8 will usually prove more satisfactory, especially when installed in sandy or sandy loam soils, or when the ditch below the structure cannot conveniently be protected against erosion by other means.

Whenever possible, metal plates of galvanized iron 1/16 inch thick (16 gage) or heavier should be used to form the notch on wooden weirs. For small weirs the notch is preferably cut from a single piece. The plates should be fastened to the structure with screws or bolts.

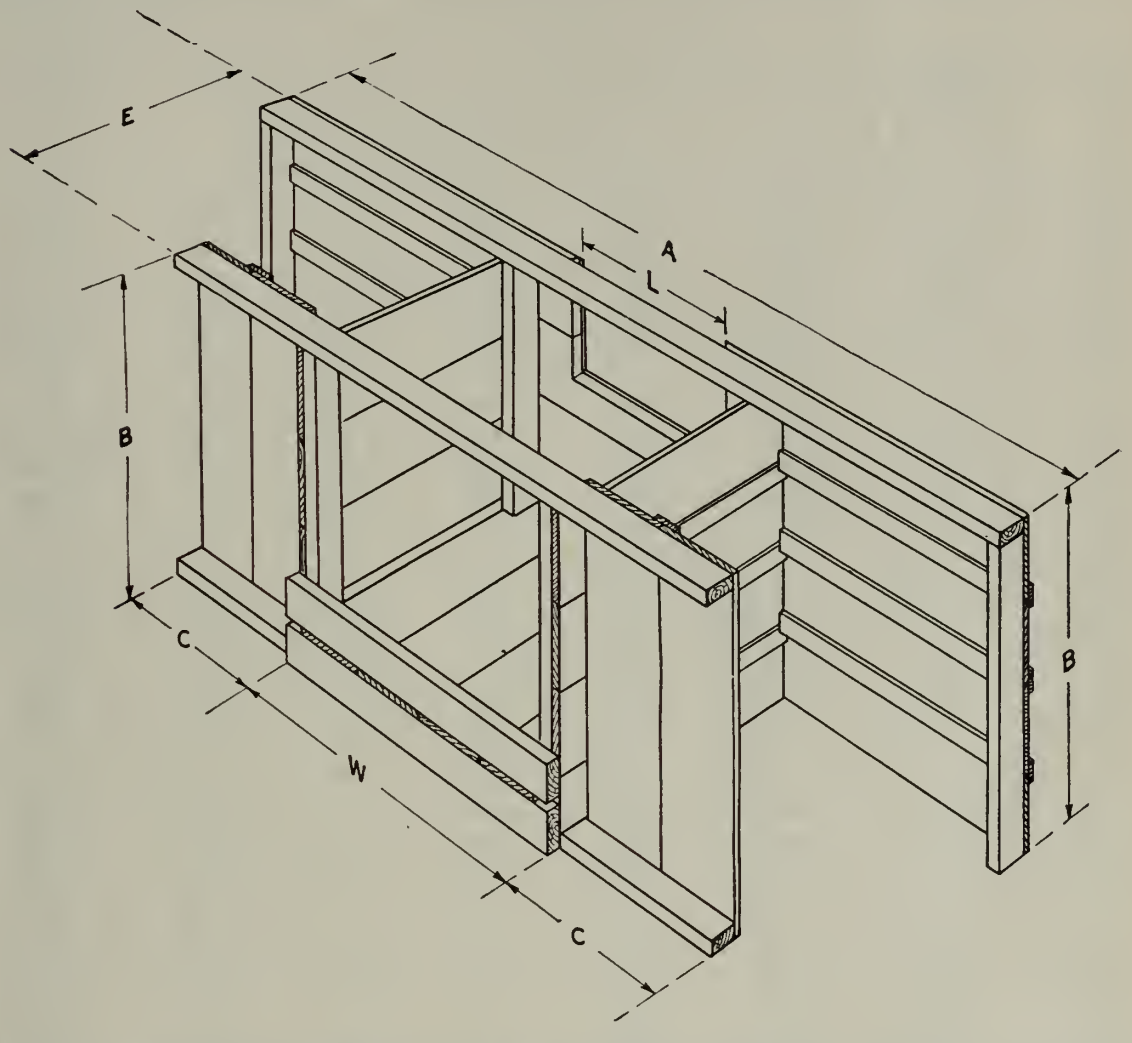


Fig. 8.—Downstream perspective of wooden weir structure. The upstream face is identical with that of the structure shown in figure 6.

Essentials of Weir Measurement.—The following general rules should be observed in the construction, installation, and use of contracted weirs. They are especially important for accurate measurements.

1. A weir should be set at right angles to the direction of flow in a channel that is straight for a distance upstream from the weir at least ten times the length of the weir crest.

2. The ditch upstream from the weir should be sufficiently large so that the water will approach the weir in a smooth stream, free from eddies, with a mean velocity of not more than a half foot per second. To avoid submergence, the crest must be placed higher than the maximum downstream elevation of the water surface. The height of the crest above the bottom of the ditch upstream from the weir should be twice the maximum head to be measured; and preferably, if accurate results are

TABLE 3

FLOW OVER RECTANGULAR CONTRACTED WEIRS IN CUBIC FEET PER SECOND*

Head in feet	Head in inches, approx.	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.10	1 1/16	0.105	0.158	0.212	0.319	0.427	0.108
0.11	1 5/16	0.121	0.182	0.244	0.367	0.491	0.124
0.12	1 7/16	0.137	0.207	0.277	0.418	0.559	0.141
0.13	1 9/16	0.155	0.233	0.312	0.470	0.629	0.159
0.14	1 11/16	0.172	0.260	0.348	0.524	0.701	0.177
0.15	1 13/16	0.191	0.288	0.385	0.581	0.776	0.196
0.16	1 15/16	0.210	0.316	0.423	0.638	0.854	0.216
0.17	2 1/16	0.229	0.346	0 463	0.698	0 934	0.236
0.18	2 3/16	0.249	0.376	0.504	0.760	1.02	0.257
0.19	2 1/4	0.270	0.407	0.546	0 823	1.10	0.278
0.20	2 3/8	0.291	0.439	0.588	0.887	1 19	0.303
0.21	2 1/2	0 312	0.472	0.632	0.954	1.28	0.326
0.22	2 5/8	0.335	0.505	0.677	1.02	1.37	0.35
0.23	2 3/4	0.358	0.539	0.723	1.09	1.46	0.37
0.24	2 7/8	0.380	0.574	0.769	1.16	1.55	0.39
0.25	3	0.404	0.609	0.817	1.23	1.65	0.42
0.26	3 1/8	0.428	0.646	0.865	1.31	1.75	0.44
0.27	3 1/4	0.452	0.682	0.914	1.38	1.85	0.47
0.28	3 3/8	0.477	0.720	0.965	1.46	1.95	0.49
0.29	3 1/2	0.502	0.758	1.02	1.53	2.05	0.52
0.30	3 5/8	0.527	0.796	1.07	1.61	2.16	0.55
0.31	3 3/4	0.553	0.836	1.12	1.69	2.26	0 57
0.32	3 13/16	0.580	0.876	1.18	1.77	2.37	0.60
0.33	3 15/16	0.606	0.916	1.23	1.86	2.48	0.62
0.34	4 1/16	0.634	0.957	1.28	1.94	2.60	0.66
0.35	4 3/16	0.661	0.999	1.34	2.02	2.71	0.69
0.36	4 5/16	0.688	1.04	1.40	2.11	2.82	0.71
0.37	4 7/16	0.717	1.08	1.45	2.20	2.94	0.74
0.38	4 9/16	0.745	1.13	1.51	2.28	3.06	0.78
0.39	4 11/16	0.774	1.17	1.57	2.37	3.18	0.81
0.40	4 13/16	0.804	1.21	1.63	2.46	3.30	0.84
0.41	4 15/16	0.833	1.26	1.69	2.55	3.42	0.87
0.42	5 1/16	0.863	1.30	1.75	2.65	3.54	0.89
0.43	5 3/16	0.893	1.35	1.81	2.74	3.67	0.93
0.44	5 1/4	0.924	1.40	1.88	2.83	3.80	0.97
0.45	5 3/8	0.955	1.44	1.94	2.93	3.93	1.00
0.46	5 1/2	0.986	1.49	2.00	3.03	4.05	1.02
0.47	5 5/8	1.02	1.54	2.07	3.12	4.18	1.06
0.48	5 3/4	1.05	1.59	2.13	3.22	4.32	1.10
0.49	5 7/8	1.08	1.64	2.20	3.32	4.45	1.13

* Computed from Cone's formula, $Q = 3.247\ L\ H^{1.48} - \frac{0.566\ L^{1.8}}{1+2\ L^{1.8}}\ H^{1.9}$.

TABLE 3—FLOW OVER RECTANGULAR CONTRACTED WEIRS—(*Continued*)

Head in feet	Head in inches, approx.	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.50	6	1.11	1.68	2.26	3.42	4.58	1.16
0.51	6 1/8	1.15	1.73	2.33	3.52	4.72	1.20
0.52	6 1/4	1.18	1.78	2.40	3.62	4.86	1.24
0.53	6 3/8	1.21	1.84	2.46	3.73	4.99	1.26
0.54	6 1/2	1.25	1.89	2.53	3.83	5.13	1.30
0.55	6 5/8	1.28	1.94	2.60	3.94	5.27	1.33
0.56	6 3/4	1.31	1.99	2.67	4.04	5.42	1.38
0.57	6 13/16	1.35	2.04	2.74	4.15	5.56	1.41
0.58	6 15/16	1.38	2.09	2.81	4.26	5 70	1.44
0.59	7 1/16	1.42	2.15	2.88	4.36	5 85	1.49
0.60	7 3/16	1.45	2.20	2.96	4.47	6.00	1.53
0.61	7 5/16	1.49	2.25	3.03	4.59	6.14	1.55
0.62	7 7/16	1.52	2.31	3.10	4.69	6.29	1.60
0.63	7 9/16	1.56	2.36	3.17	4.81	6.44	1.63
0.64	7 11/16	1.60	2.42	3.25	4.92	6.59	1.67
0.65	7 13/16	1.63	2.47	3.32	5.03	6.75	1.72
0.66	7 15/16	1.67	2.53	3.40	5.15	6.90	1.75
0.67	8 1/16	1 71	2.59	3.47	5.26	7.05	1.79
0.68	8 3/16	1.74	2.64	3.56	5.38	7.21	1.83
0.69	8 1/4	1.78	2.70	3.63	5.49	7.36	1.87
0.70	8 3/8	1.82	2.76	3.71	5.61	7.52	1.91
0.71	8 1/2	1.86	2.81	3.78	5.73	7.68	1.95
0.72	8 5/8	1.90	2.87	3.86	5.85	7.84	1.99
0.73	8 3/4	1.93	2.93	3.94	5.97	8.00	2.03
0.74	8 7/8	1.97	2.99	4.02	6.09	8.17	2.08
0.75	9	2.01	3.05	4.10	6.21	8.33	2.12
0.76	9 1/8	2.05	3.11	4.18	6.33	8.49	2.16
0.77	9 1/4	2.09	3.17	4.26	6.45	8.66	2.21
0.78	9 3/8	2.13	3.23	4.34	6.58	8.82	2.24
0.79	9 1/2	2.17	3.29	4.42	6.70	8.99	2.29
0.80	9 5/8	2.21	3.35	4.51	6.83	9.16	2.33
0.81	9 3/4	2.25	3.41	4.59	6.95	9.33	2.38
0.82	9 13/16	2.29	3.47	4.67	7.08	9.50	2.42
0 83	9 15/16	2.33	3 54	4.75	7.21	9.67	2.46
0.84	10 1/16	2.37	3.60	4.84	7.33	9.84	2.51
0.85	10 3/16	2.41	3 66	4.92	7.46	10.01	2.55
0.86	10 5/16	2.46	3.72	5.01	7.59	10.19	2.60
0.87	10 7/16	2.50	3.79	5.10	7.72	10.36	2.64
0.88	10 9/16	2.54	3.85	5.18	7.85	10.54	2.69
0.89	10 11/16	2.58	3.92	5.27	7.99	10.71	2 72
0.90	10 13/16	2.62	3.98	5 35	8.12	10.89	2.77
0.91	10 15/16	2.67	4.05	5.44	8.25	11.07	2.82
0.92	11 1/16	2.71	4.11	5.53	8.38	11.25	2.87
0.93	11 3/16	2.75	4.18	5.62	8.52	11.43	2.91
0.94	11 1/4	2.79	4.24	5.71	8.65	11.61	2.96

TABLE 3—FLOW OVER RECTANGULAR CONTRACTED WEIRS—(*Continued*)

Head in feet	Head in inches, approx.	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.95	11 3/8	2.84	4.31	5 80	8.79	11.79	3.00
0.96	11 1/2	2.88	4.37	5.89	8.93	11 98	3 05
0.97	11 5/8	2.93	4.44	5.98	9.06	12.16	3.10
0.98	11 3/4	2.97	4.51	6.07	9.20	12 34	3.14
0.99	11 7/8	3.01	4.57	6.15	9.34	12.53	3.19
1.00	12	3.06	4.64	6.25	9.48	12 72	3.24
1 01	12 1/8	.....	4.71	6.34	9.62	12 91	3.29
1.02	12 1/4	.....	4.78	6.43	9.76	13.10	3 34
1.03	12 3/8	.....	4.85	6.52	9.90	13 28	3.38
1.04	12 1/2	.....	4.92	6.62	10 04	13.47	3.43
1.05	12 5/8	.....	4.98	6.71	10.18	13.66	3.48
1.06	12 3/4	.....	5.05	6.80	10.32	13.85	3 53
1.07	12 13/16	.....	5 12	6.90	10.46	14.04	3.58
1.08	12 15/16	.....	5 20	6 99	10.61	14.24	3.63
1.09	13 1/16	.....	5.26	7 09	10 75	14.43	3.68
1.10	13 3/16	.....	5.34	7.19	10.90	14 64	3.74
1.11	13 5/16	.....	5.41	7.28	11.04	14.83	3.79
1.12	13 7/16	.....	5.48	7.38	11.19	15.03	3.84
1.13	13 9/16	.....	5.55	7.47	11 34	15.22	3.88
1.14	13 11/16	.....	5.62	7.57	11.48	15.42	3.94
1.15	13 13/16	.....	5.69	7.66	11.64	15.62	3.98
1.16	13 15/16	.....	5.77	7.76	11.79	15.82	4.03
1.17	14 1/16	.....	5.84	7.86	11.94	16.02	4.08
1.18	14 3/16	.....	5 91	7.96	12.09	16.23	4.14
1.19	14 1/4	.....	5.98	8.06	12.24	16.43	4.19
1.20	14 3/8	.....	6.06	8.16	12.39	16.63	4.24
1.21	14 1/2	.....	6.13	8.26	12.54	16.83	4.29
1.22	14 5/8	.....	6.20	8.35	12.69	17.03	4.34
1.23	14 3/4	.....	6.28	8.46	12.85	17.25	4.40
1.24	14 7/8	.....	6.35	8.56	12.99	17.45	4.46
1.25	15	.....	6.43	8.66	13.14	17.65	4.51
1.26	15 1/8	.....	.....	.....	13 30	17.87	4.57
1 27	15 1/4	.....	.....	.....	13.45	18.07	4.62
1 28	15 3/8	.....	.....	.....	13.61	18.28	4.67
1.29	15 1/2	.....	.....	.....	13.77	18.50	4.73
1.30	15 5/8	.....	.....	.....	13.93	18.71	4.78
1 31	15 3/4	.....	.....	.....	14.09	18.92	4.82
1.32	15 13/16	.....	.....	.....	14.24	19.12	4.88
1 33	15 15/16	.....	.....	.....	14.40	19.34	4.94
1.34	16 1/16	.....	.....	.....	14.56	19.55	4.99
1.35	16 3/16	.....	.....	.....	14.72	19.77	5.05
1.36	16 5/16	.....	.....	.....	14.88	19.98	5.10
1.37	16 7/16	.....	.....	.....	15.04	20.20	5.16
1.38	16 9/16	.....	.....	.....	15.20	20.42	5.22
1.39	16 11/16	.....	.....	.....	15.36	20.64	5.28

TABLE 3—FLOW OVER RECTANGULAR CONTRACTED WEIRS—(*Concluded*)

Head in feet	Head in inches, approx.	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
1.40	16 13/16	.....	.....	.....	15.53	20.86	5.33
1.41	16 15/16	.....	.....	.....	15.69	21.08	5.39
1.42	17 1/16	.....	.....	.....	15.85	21.29	5.44
1.43	17 3/16	.....	.....	.....	16.02	21.52	5.50
1.44	17 1/4	.....	.....	.....	16.19	21.74	5.55
1.45	17 3/8	.....	.....	.....	16.34	21.96	5.62
1.46	17 1/2	.....	.....	.....	16.51	22.18	5.67
1.47	17 5/8	.....	.....	.....	16.68	22.41	5.73
1.48	17 3/4	.....	.....	.....	16.85	22.64	5.79
1.49	17 7/8	.....	.....	.....	17.01	22.85	5.84
1.50	18	.....	.....	.....	17.17	23.08	5.91

desired, it should be more than this amount. The distance from the side of the weir notch to the sides of the ditch should also be twice the maximum head. If the ditch is not sufficiently large, the contractions of the nappe will be incomplete, the velocity of approach will be too high, and the flow over the weir will be greater than given in the tables unless a correction for velocity of approach is made. The error in measurement caused by incomplete contractions and by velocity of approach may be as much as 10 or 15 per cent.

3. The weir crest must be straight and level, and the upstream face of the weir vertical and smooth, especially near the notch. The crest and sides of the notch should not exceed ¼ inch in thickness, with a sharp right-angle upstream corner, since a rounded one will decrease the head for a given flow. The length of the weir crest should be accurately determined, for the percentage of error in flow is directly proportional to that made in determining the length of the weir crest.

4. The head, or vertical distance from the weir crest to the water level upstream from the weir, should be measured far enough from the notch so that it will not be affected by the downward curve of the water surface. The gage may be a rule or scale graduated in inches and sixteenths or—preferably—in feet and tenths and hundredths of a foot. The measurement may be made near the upstream face of the weir if at a sufficient distance to one side of the notch to be in comparatively still water. Sometimes the gage may conveniently be fastened to the upstream face of the weir; if so, it should be at least a foot from the notch—farther if possible. More often it is placed 3 or 4 feet upstream from the weir and

TABLE 4

FLOW OVER RECTANGULAR CONTRACTED WEIRS IN GALLONS PER MINUTE*

Head in feet	Head in inches, approx.	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in gallons per minute					
0.10	1 3/16	47	71	95	143	192	49
0.11	1 5/16	54	82	110	165	220	55
0.12	1 7/16	61	93	125	188	251	63
0.13	1 9/16	70	105	140	211	282	71
0.14	1 11/16	77	117	156	235	315	80
0.15	1 13/16	86	129	173	260	348	88
0.16	1 15/16	94	142	190	286	383	97
0.17	2 1/16	103	155	208	313	419	106
0.18	2 3/16	112	168	226	341	456	115
0.19	2 1/4	121	182	245	369	494	125
0.20	2 3/8	131	197	264	398	533	135
0.21	2 1/2	140	212	284	428	573	145
0.22	2 5/8	150	227	304	458	614	156
0.23	2 3/4	161	242	325	489	655	166
0.24	2 7/8	171	258	346	521	697	176
0.25	3	181	274	367	554	741	187
0.26	3 1/8	192	290	388	587	785	198
0.27	3 1/4	203	306	410	620	830	210
0.28	3 3/8	214	323	434	654	875	221
0.29	3 1/2	225	340	457	688	921	233
0.30	3 5/8	237	357	480	723	968	245
0.31	3 3/4	248	375	504	759	1,020	257
0.32	3 13/16	260	393	528	795	1,060	270
0.33	3 15/16	272	411	552	832	1,110	282
0.34	4 1/16	285	430	576	869	1,170	295
0.35	4 3/16	297	448	601	907	1,220	308
0.36	4 5/16	309	467	627	945	1,270	322
0.37	4 7/16	322	486	653	984	1,320	336
0.38	4 9/16	334	505	679	1,020	1,370	350
0.39	4 11/16	347	525	705	1,060	1,430	364
0.40	4 13/16	361	545	731	1,100	1,480	377
0.41	4 15/16	374	565	758	1,140	1,530	390
0.42	5 1/16	387	585	785	1,190	1,590	402
0.43	5 3/16	401	606	812	1,230	1,650	416
0.44	5 1/4	415	627	842	1,270	1,700	431
0.45	5 3/8	429	648	870	1,320	1,760	445
0.46	5 1/2	443	669	898	1,360	1,820	459
0.47	5 5/8	457	690	927	1,400	1,880	473
0.48	5 3/4	471	711	956	1,450	1,940	490
0.49	5 7/8	486	733	985	1,490	2,000	505

* Computed from Cone's formula, g.p.m. $= 448.8 \left[3.247\, L\, H^{1.48} - \frac{0.566\, L^{1.8}}{1+2\, L^{1.8}}\, H^{1.9}\right]$.

TABLE 4—FLOW OVER RECTANGULAR CONTRACTED WEIRS—(*Continued*)

Head in feet	Head in inches, approx.	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in gallons per minute					
0.50	6	501	754	1,020	1,530	2,060	522
0.51	6 1/8	516	777	1,050	1,580	2,120	538
0.52	6 1/4	531	800	1,080	1,620	2,180	554
0.53	6 3/8	546	823	1,110	1,670	2,240	566
0.54	6 1/2	561	846	1,140	1,720	2,300	583
0.55	6 5/8	576	869	1,170	1,770	2,370	600
0.56	6 3/4	591	892	1,200	1,810	2,430	617
0.57	6 13/16	606	915	1,230	1,860	2,490	634
0.58	6 15/16	621	938	1,260	1,910	2,560	650
0.59	7 1/16	637	961	1,290	1,960	2,620	666
0.60	7 3/16	653	985	1,330	2,010	2,690	683
0.61	7 5/16	669	1,010	1,360	2,060	2,760	699
0.62	7 7/16	685	1,040	1,390	2,110	2,820	716
0.63	7 9/16	700	1,060	1,420	2,160	2,890	733
0.64	7 11/16	716	1,090	1,460	2,210	2,960	750
0.65	7 13/16	732	1,110	1,490	2,260	3,030	767
0.66	7 15/16	749	1,140	1,520	2,310	3,100	784
0.67	8 1/16	766	1,160	1,560	2,360	3,160	801
0.68	8 3/16	783	1,190	1,590	2,420	3,230	819
0.69	8 1/4	799	1,210	1,630	2,470	3,300	837
0.70	8 3/8	816	1,240	1,660	2,520	3,380	856
0.71	8 1/2	833	1,260	1,700	2,570	3,450	875
0.72	8 5/8	850	1,290	1,730	2,630	3,520	894
0.73	8 3/4	867	1,320	1,770	2,680	3,590	913
0.74	8 7/8	884	1,340	1,800	2,730	3,670	932
0.75	9	902	1,370	1,840	2,790	3,740	951
0.76	9 1/8	920	1,400	1,880	2,840	3,810	970
0.77	9 1/4	938	1,420	1,910	2,900	3,890	990
0.78	9 3/8	956	1,450	1,950	2,950	3,960	1,010
0.79	9 1/2	974	1,480	1,980	3,010	4,040	1,030
0.80	9 5/8	992	1,500	2,020	3,060	4,110	1,050
0.81	9 3/4	1,010	1,530	2,060	3,120	4,190	1,070
0.82	9 13/16	1,030	1,560	2,100	3,180	4,260	1,090
0.83	9 15/16	1,050	1,590	2,130	3,230	4,340	1,110
0.84	10 1/16	1,060	1,610	2,170	3,290	4,420	1,130
0.85	10 3/16	1,080	1,640	2,210	3,350	4,490	1,150
0.86	10 5/16	1,100	1,670	2,250	3,410	4,570	1,170
0.87	10 7/16	1,120	1,700	2,280	3,460	4,650	1,190
0.88	10 9/16	1,140	1,730	2,320	3,520	4,730	1,210
0.89	10 11/16	1,160	1,760	2,360	3,580	4,810	1,230

TABLE 4—FLOW OVER RECTANGULAR CONTRACTED WEIRS—(*Concluded*)

Head in feet	Head in inches, approx.	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in gallons per minute					
0.90	10 13/16	1,180	1,790	2,400	3,640	4,890	1,250
0.91	10 15/16	1,200	1,820	2,440	3,700	4,970	1,270
0.92	11 1/16	1,220	1,850	2,480	3,760	5,050	1,290
0.93	11 3/16	1,230	1,870	2,520	3,820	5,130	1,310
0.94	11 1/4	1,250	1,900	2,560	3,880	5,210	1,330
0.95	11 3/8	1,270	1,930	2,600	3,940	5,290	1,350
0.96	11 1/2	1,290	1,960	2,640	4,000	5,380	1,370
0.97	11 5/8	1,320	1,990	2,680	4,070	5,460	1,390
0.98	11 3/4	1,330	2,020	2,720	4,130	5,540	1,410
0.99	11 7/8	1,350	2,050	2,760	4,190	5,620	1,430
1.00	12	1,370	2,080	2,800	4,260	5,710	1,450

near one side of the channel. The zero point on the gage should be set level with the weir crest with a carpenter's or engineer's level. A common method is to set a stake in the ditch upstream with its top level with the weir crest, and to measure the head from the top of the stake to the water surface with a rule. For greater accuracy, a hook gage and stilling well are recommended (see p. 81–84). Careful measurements are important because the percentage of error in flow is approximately 1.5 times that made in measuring the head for rectangular and Cipolletti weirs, and 2.5 times that made in measuring the head for 90-degree triangular notch weirs. For example, an error of 0.01 foot in measuring a head of 0.1 foot will result in an error of 15 per cent for rectangular and Cipolletti weirs, and 25 per cent for a triangular weir.

5. The length of the weir crest should be such that the minimum head to be measured will not be less than about 2 inches, and the maximum preferably not more than one-third the length of the weir crest. Accurate measurements can be made when the heads are greater than this provided the channel is sufficiently large to produce complete contractions and a very low velocity of approach. It is, however, difficult to measure heads less than 2 inches with sufficient accuracy; and experimental data are lacking for substantiating the formulas for these small heads.

Limitations in the Use of Weirs.—Although weirs are easy to construct and convenient to use, they are not always suitable. They are not accurate unless proper conditions for weir measurements are maintained. They require a considerable loss of head, often not available in

TABLE 5

FLOW OVER CIPOLLETTI WEIRS IN CUBIC FEET PER SECOND*

Head in feet	Head in inches, approx.	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.10	1 3/16	0.107	0.160	0.214	0.321	0.429	0.108
0.11	1 5/16	0.123	0.185	0.246	0.370	0.494	0.124
0.12	1 7/16	0.140	0.210	0.280	0.421	0.562	0.141
0.13	1 9/16	0.158	0.237	0.316	0.474	0.632	0.159
0.14	1 11/16	0.177	0.264	0.352	0.528	0.706	0.177
0.15	1 13/16	0.195	0.293	0.390	0.586	0.782	0.196
0.16	1 15/16	0.216	0.322	0.430	0.644	0.860	0.216
0.17	2 1/16	0.237	0.353	0.470	0.705	0.941	0.236
0.18	2 3/16	0.258	0.384	0.512	0.768	1.024	0.257
0.19	2 1/4	0.280	0.417	0.555	0.832	1.110	0.278
0.20	2 3/8	0.302	0.450	0.599	0.898	1.20	0.302
0.21	2 1/2	0.324	0.484	0.644	0.966	1.29	0.324
0.22	2 5/8	0.349	0.519	0.691	1.04	1.38	0.35
0.23	2 3/4	0.374	0.555	0.739	1.11	1.47	0.37
0.24	2 7/8	0.397	0.591	0.786	1.18	1.57	0.39
0.25	3	0.423	0.628	0.836	1.25	1.67	0.42
0.26	3 1/8	0.449	0.667	0.886	1.33	1.77	0.44
0.27	3 1/4	0.475	0.705	0.937	1.40	1.87	0.47
0.28	3 3/8	0.502	0.745	0.990	1.48	1.97	0.49
0.29	3 1/2	0.529	0.785	1.04	1.56	2.08	0.52
0.30	3 5/8	0.557	0.827	1.10	1.64	2.19	0.55
0.31	3 3/4	0.586	0.869	1.15	1.73	2.30	0.57
0.32	3 13/16	0.615	0.911	1.21	1.81	2.41	0.60
0.33	3 15/16	0.644	0.954	1.27	1.89	2.52	0.62
0.34	4 1/16	0.675	1.00	1.32	1.98	2.64	0.66
0.35	4 3/16	0.705	1.04	1.38	2.07	2.75	0.69
0.36	4 5/16	0.735	1.09	1.44	2.16	2.87	0.71
0.37	4 7/16	0.767	1.13	1.50	2.25	2.99	0.74
0.38	4 9/16	0.799	1.18	1.57	2.34	3.11	0.78
0.39	4 11/16	0.832	1.23	1.63	2.43	3.24	0.81
0.40	4 13/16	0.866	1.28	1.69	2.53	3.36	0.84
0.41	4 15/16	0.899	1.32	1.76	2.62	3.49	0.87
0.42	5 1/16	0.932	1.37	1.82	2.72	3.61	0.89
0.43	5 3/16	0.967	1.42	1.89	2.81	3.74	0.93
0.44	5 1/4	1.00	1.47	1.95	2.91	3.87	0.97
0.45	5 3/8	1.04	1.53	2.02	3.01	4.01	1.00
0.46	5 1/2	1.07	1.58	2.09	3.11	4.14	1.02
0.47	5 5/8	1.11	1.63	2.16	3.21	4.28	1.06
0.48	5 3/4	1.15	1.68	2.23	3.32	4.41	1.10
0.49	5 7/8	1.18	1.74	2.30	3.42	4.55	1.13

* Computed from Cone's formula $Q = 3.247\ L\ H^{1.48} - \frac{0.566\ L^{1.8}}{1+2\ L^{1.8}}\ H^{1.9} + 0.609\ H^{2.5}$.

TABLE 5—FLOW OVER CIPOLLETTI WEIRS—(*Continued*)

Head in feet	Head in inches, approx.	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.50	6	1.22	1.79	2.37	3.53	4.69	1.16
0.51	6 1/8	1.26	1.85	2.44	3.64	4.83	1.20
0.52	6 1/4	1.30	1.90	2.51	3.74	4.97	1.24
0.53	6 3/8	1.34	1.96	2.59	3.85	5.12	1.26
0.54	6 1/2	1.38	2.02	2.66	3.96	5.26	1.30
0.55	6 5/8	1.42	2.07	2.74	4.07	5.41	1.33
0.56	6 3/4	1.46	2.13	2.81	4.18	5.56	1.38
0.57	6 13/16	1.50	2.19	2.89	4.30	5.71	1.41
0.58	6 15/16	1.54	2.25	2.97	4.41	5.86	1.44
0.59	7 1/16	1.58	2.31	3.05	4.53	6.01	1.49
0.60	7 3/16	1.62	2.37	3.13	4.64	6.17	1.53
0.61	7 5/16	1.67	2.43	3.20	4.76	6.32	1.55
0.62	7 7/16	1.71	2.49	3.28	4.88	6.47	1.60
0.63	7 9/16	1.75	2.55	3.37	5.00	6.63	1.63
0.64	7 11/16	1.80	2.62	3.45	5.12	6.79	1.67
0.65	7 13/16	1.84	2.68	3.53	5.24	6.95	1.72
0.66	7 15/16	1.89	2.75	3.61	5.36	7.11	1.75
0.67	8 1/16	1.93	2.81	3.70	5.48	7.28	1.79
0.68	8 3/16	1.98	2.87	3.79	5.61	7.44	1.83
0.69	8 1/4	2.02	2.94	3.87	5.73	7.61	1.87
0.70	8 3/8	2.07	3.01	3.95	5.86	7.77	1.91
0.71	8 1/2	2.12	3.07	4.04	5.99	7.94	1.95
0.72	8 5/8	2.16	3.14	4.13	6.12	8.11	1.99
0.73	8 3/4	2.21	3.21	4.22	6.24	8.28	2.03
0.74	8 7/8	2.26	3.28	4.31	6.38	8.45	2.08
0.75	9	2.31	3.35	4.40	6.51	8.62	2.12
0.76	9 1/8	2.36	3.42	4.49	6.64	8.80	2.16
0.77	9 1/4	2.41	3.49	4.58	6.77	8.97	2.21
0.78	9 3/8	2.46	3.56	4.67	6.90	9.15	2.24
0.79	9 1/2	2.51	3.63	4.76	7.04	9.33	2.29
0.80	9 5/8	2.56	3.70	4.85	7.18	9.51	2.33
0.81	9 3/4	2.61	3.77	4.95	7.31	9.69	2.38
0.82	9 13/16	2.66	3.84	5.04	7.45	9.87	2.42
0.83	9 15/16	2.71	3.92	5.14	7.59	10.05	2.46
0.84	10 1/16	2.77	3.99	5.23	7.73	10.23	2.51
0.85	10 3/16	2.82	4.07	5.33	7.87	10.42	2.55
0.86	10 5/16	2.87	4.14	5.43	8.01	10.60	2.60
0.87	10 7/16	2.93	4.22	5.52	8.15	10.79	2.64
0.88	10 9/16	2.98	4.29	5.62	8.30	10.98	2.69
0.89	10 11/16	3.04	4.37	5.72	8.44	11.17	2.72

TABLE 5—FLOW OVER CIPOLLETTI WEIRS—(*Continued*)

Head in feet	Head in inches, approx.	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.90	10 13/16	3.09	4.45	5.82	8.59	11.36	2.77
0.91	10 15/16	3.15	4.53	5.92	8.73	11.55	2.82
0.92	11 1/16	3.20	4.60	6.02	8.88	11.74	2.87
0.93	11 3/16	3.26	4.68	6.13	9.03	11.94	2.91
0.94	11 1/4	3.32	4.76	6.23	9.17	12.13	2.96
0.95	11 3/8	3.37	4.84	6.33	9.32	12.33	3.00
0.96	11 1/2	3.43	4.92	6.44	9.48	12.53	3.05
0.97	11 5/8	3.49	5.00	6.55	9.62	12.72	3.10
0.98	11 3/4	3.55	5.09	6.64	9.78	12.92	3.14
0.99	11 7/8	3.61	5.17	6.75	9.93	13.12	3.19
1.00	12	3.67	5.25	6.86	10.08	13.32	3.24
1.01	12 1/8	.....	5.33	6.96	10.24	13.53	3.29
1.02	12 1/4	.....	5.42	7.07	10.40	13.73	3.34
1.03	12 3/8	.....	5.50	7.18	10.55	13.94	3.38
1.04	12 1/2	.....	5.59	7.29	10.71	14.15	3.43
1.05	12 5/8	.....	5.67	7.40	10.87	14.35	3.48
1.06	12 3/4	.....	5.76	7.51	11.03	14.56	3.53
1.07	12 13/16	.....	5.84	7.62	11.18	14.76	3.58
1.08	12 15/16	.....	5.93	7.73	11.35	14.98	3.63
1.09	13 1/16	.....	6.02	7.84	11.51	15.19	3.68
1.10	13 3/16	.....	6.11	7.96	11.68	15.41	3.74
1.11	13 5/16	.....	6.20	8.07	11.84	15.62	3.79
1.12	13 7/16	.....	6.29	8.18	12.00	15.84	3.84
1.13	13 9/16	.....	6.37	8.29	12.16	16.04	3.88
1.14	13 11/16	.....	6.46	8.41	12.33	16.26	3.94
1.15	13 13/16	.....	6.56	8.53	12.50	16.48	3.98
1.16	13 15/16	.....	6.65	8.65	12.67	16.70	4.03
1.17	14 1/16	.....	6.74	8.76	12.84	16.93	4.08
1.18	14 3/16	.....	6.83	8.88	13.01	17.15	4.14
1.19	14 1/4	.....	6.93	9.00	13.18	17.37	4.19
1.20	14 3/8	.....	7.02	9.12	13.35	17.59	4.24
1.21	14 1/2	.....	7.11	9.24	13.52	17.81	4.29
1.22	14 5/8	.....	7.20	9.36	13.69	18.03	4.34
1.23	14 3/4	.....	7.30	9.48	13.87	18.27	4.40
1.24	14 7/8	.....	7.40	9.60	14.04	18.49	4.46
1.25	15	.....	7.49	9.72	14.21	18.71	4.51
1.26	15 1/8	.....	.....	.....	14.39	18.95	4.57
1.27	15 1/4	.....	.....	.....	14.56	19.17	4.62
1.28	15 3/8	.....	.....	.....	14.74	19.41	4.67
1.29	15 1/2	.....	.....	.....	14.92	19.65	4.73

TABLE 5—FLOW OVER CIPOLLETTI WEIRS—(*Concluded*)

Head in feet	Head in inches, approx.	Crest length					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
1.30	15 5/8	.....	.....	.....	15.11	19.88	4.78
1.31	15 3/4	.....	.....	.....	15.29	20.12	4.82
1.32	15 13/16	.....	.....	.....	15.46	20.34	4.88
1.33	15 15/16	.....	.....	.....	15.64	20.58	4.94
1.34	16 1/16	.....	.....	.....	15.82	20.82	4.99
1.35	16 3/16	.....	.....	.....	16.01	21.06	5.05
1.36	16 5/16	.....	.....	.....	16.19	21.29	5.10
1.37	16 7/16	.....	.....	.....	16.37	21.53	5.16
1.38	16 9/16	.....	.....	.....	16.57	21.78	5.22
1.39	16 11/16	.....	.....	.....	16.75	22.02	5.28
1.40	16 13/16	.....	.....	.....	16.94	22.27	5.33
1.41	16 15/16	.....	.....	.....	17.13	22.51	5.39
1.42	17 1/16	.....	.....	.....	17.31	22.75	5.44
1.43	17 3/16	.....	.....	.....	17.51	23.01	5.50
1.44	17 1/4	.....	.....	.....	17.70	23.26	5.55
1.45	17 3/8	.....	.....	.....	17.89	23.50	5.62
1.46	17 1/2	.....	.....	.....	18.08	23.75	5.67
1.47	17 5/8	.....	.....	.....	18.28	24.01	5.73
1.48	17 3/4	.....	.....	.....	18.47	24.26	5.79
1.49	17 7/8	.....	.....	.....	18.66	24.50	5.84
1.50	18	.....	.....	.....	18.85	24.75	5.91

ditches on flat grades. They are not easily combined with turnout structures and usually require the installation and maintenance, at considerable expense, of separate structures for measuring purposes. Finally, they are not suitable for water carrying silt, which deposits in the channel of approach and destroys the proper conditions for weir measurements.

Weir Tables.—Table 3 (p. 18) gives the flow over rectangular contracted weirs in cubic feet per second for heads up to 1½ feet; table 4, in gallons per minute for heads up to 1 foot. (The latter table will be found useful in measuring the flow from pumping plants). Table 5 gives the flow over Cipolletti weirs in cubic feet per second for heads up to 1½ feet. Table 6 gives the flow over 90-degree triangular notch weirs in cubic feet per second and in gallons per minute for heads up to 1¼ feet.

All these tables have been computed from Cone's[5] formulas, considered the most reliable for small weirs and for conditions generally encountered in measuring water for irrigation.

[5] Cone, V. M. Flow through weir notches with thin edges and full contractions. Jour. Agr. Research 5(23):1094. 1916.

TABLE 6

FLOW OVER 90-DEGREE TRIANGULAR-NOTCH WEIR IN CUBIC FEET PER SECOND AND GALLONS PER MINUTE*

Head in feet	Head in inches, approx.	Flow in cubic feet per second	Flow in gallons per minute
0.10	1 3/16	0.008	3.6
0.11	1 5/16	0.010	4.6
0.12	1 7/16	0.012	5.7
0.13	1 9/16	0.016	6.8
0 14	1 11/16	0.019	8.1
0.15	1 13/16	0.022	9.5
0 16	1 15/16	0.026	11.2
0.17	2 1/16	0.031	13.1
0.18	2 3/16	0.035	15.2
0 19	2 1/4	0.040	17.5
0.20	2 3/8	0.046	19.9
0.21	2 1/2	0.052	22.5
0.22	2 5/8	0.058	25.3
0.23	2 3/4	0.065	28.3
0.24	2 7/8	0.072	31.6
0.25	3	0.080	35.1
0.26	3 1/8	0.088	38.3
0.27	3 1/4	0.096	42.8
0 28	3 3/8	0.106	47.0
0.29	3 1/2	0.115	51.4
0.30	3 5/8	0.125	56.0
0.31	3 3/4	0.136	60.8
0.32	3 13/16	0.147	65.8
0.33	3 15/16	0.159	71.1
0.34	4 1/16	0.171	76.7
0.35	4 3/16	0.184	82.6
0.36	4 5/16	0.197	88.8
0.37	4 7/16	0.211	95.0
0.38	4 9/16	0.226	101.0
0.39	4 11/16	0.240	108.0
0.40	4 13/16	0.256	115
0.41	4 15/16	0.272	122
0.42	5 1/16	0.289	130
0.43	5 3/16	0.306	137
0.44	5 1/4	0.324	145
0.45	5 3/8	0.343	154
0.46	5 1/2	0.362	162
0.47	5 5/8	0.382	171
0.48	5 3/4	0.403	181
0.49	5 7/8	0.424	190
0.50	6	0.445	200
0.51	6 1/8	0.468	210
0.52	6 1/4	0.491	220
0.53	6 3/8	0.515	231
0.54	6 1/2	0.539	242

* Computed from Cone's formulas $Q = 2.49\ H^{2.48}$
G.p.m. $= 448.8\ (2.49\ H^{2.48})$.

TABLE 6—FLOW OVER TRIANGULAR-NOTCH WEIR—(*Continued*)

Head in feet	Head in inches, approx.	Flow in cubic feet per second	Flow in gallons per minute
0.55	6 5/8	0.564	253
0.56	6 3/4	0.590	265
0.57	6 13/16	0.617	277
0.58	6 15/16	0.644	289
0.59	7 1/16	0.672	302
0.60	7 3/16	0.700	315
0.61	7 5/16	0.730	328
0.62	7 7/16	0.760	341
0.63	7 9/16	0.790	355
0.64	7 11/16	0.822	369
0.65	7 13/16	0.854	383
0.66	7 15/16	0.887	398
0.67	8 1/16	0.921	413
0.68	8 1/16	0.955	429
0.69	8 1/4	0.991	445
0.70	8 3/8	1.03	461
0.71	8 1/2	1.06	477
0.72	8 5/8	1.10	494
0.73	8 3/4	1.14	512
0.74	8 7/8	1.18	530
0.75	9	1.22	548
0.76	9 1/8	1.26	566
0.77	9 1/4	1.30	585
0.78	9 3/8	1.34	604
0.79	9 1/2	1.39	624
0.80	9 5/8	1.43	644
0.81	9 3/4	1.48	664
0.82	9 13/16	1.52	684
0.83	9 15/16	1.57	704
0.84	10 1/16	1.61	725
0.85	10 3/16	1.66	746
0.86	10 5/16	1.71	768
0.87	10 7/16	1.76	790
0.88	10 9/16	1.81	812
0.89	10 11/16	1.86	835
0.90	10 13/16	1.92	858
0.91	10 15/16	1.97	882
0.92	11 1/16	2.02	906
0.93	11 3/16	2.08	931
0.94	11 1/4	2.13	956
0.95	11 3/8	2.19	983
0.96	11 1/2	2.25	1,010
0.97	11 5/8	2.31	1,040
0.98	11 3/4	2.37	1,060
0.99	11 7/8	2.43	1,090

TABLE 6—FLOW OVER TRIANGULAR-NOTCH WEIR—(*Concluded*)

Head in feet	Head in inches, approx.	Flow in cubic feet per second	Flow in gallons per minute
1.00	12	2.49	1,120
1.01	12⅛	2.55	1,140
1.02	12¼	2.61	1,170
1.03	12⅜	2.68	1,200
1.04	12½	2.74	1,230
1.05	12⅝	2.81	1,260
1.06	12¾	2.87	1,290
1.07	12 13/16	2.94	1,320
1.08	12 15/16	3.01	1,350
1.09	13 1/16	3.08	1,380
1.10	13 3/16	3.15	1,410
1.11	13 5/16	3.22	1,440
1.12	13 7/16	3.30	1,480
1.13	13 9/16	3.37	1,510
1.14	13 11/16	3.44	1,540
1.15	13 13/16	3.52	1,580
1.16	13 15/16	3.59	1,610
1.17	14 1/16	3.67	1,650
1.18	14 3/16	3.75	1,680
1.19	14¼	3.83	1,720
1.20	14⅜	3.91	1,760
1.21	14½	3.99	1,790
1.22	14⅝	4.07	1,830
1.23	14¾	4.16	1,870
1.24	14⅞	4.24	1,900
1.25	15	4.33	1,940

Clausen-Pierce Weir Gage.—The Clausen-Pierce Weir Gage was developed on the Salt River Project, Phoenix, Arizona. The present instrument (fig. 9) is the outgrowth of a simple gage[6] used to measure the flow over free-flowing weirs. The original gage was a rod 1 inch thick and 1⅜ inches wide. A scale on the wide face was graduated in Arizona miner's inches (1/40 cubic foot per second) per inch of weir crest to give the correct measurement when held in a vertical position on the weir crest. The convenience of such a gage is obvious.

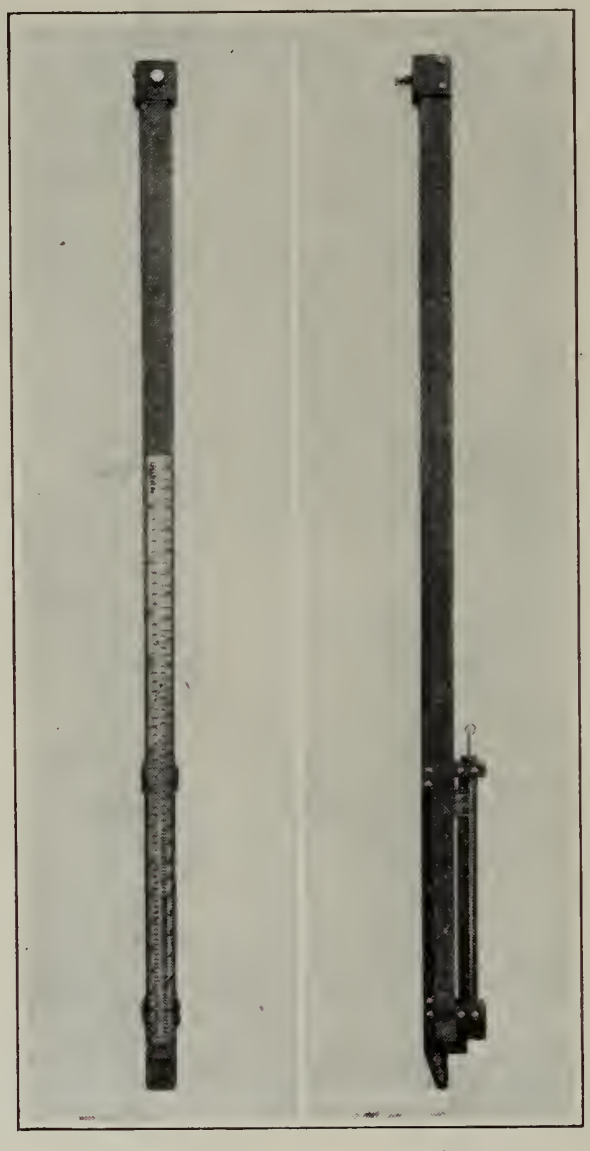
The present weir gage[7] embodies the same scale as the original and in addition is arranged for measuring the flow over submerged weirs.

This gage is based on the theory that the flow over a submerged weir equals the sum of the flow over a free-flowing weir and the flow through

[6] Hayden, T. A. Weir stick for use on narrow canals or streams. Engineering News Record 96(21):850. 1926.

[7] Lippincott, J. B. Hydraulic measuring stick. Western Construction News 4(16): 424. 1929.

a submerged orifice, each measured under a head equal to the drop in the water level through the structure. The orifice is assumed to occupy the area from weir crest to downstream water level, and the weir to occupy the area above this level.



A B

Fig. 9.—Clausen-Pierce weir gage: *A*, front view; *B*, side view.

The principal value of the gage lies in its use with submerged weirs, which may be relatively inexpensive structures. Because measurements can be made with a minimum loss of head, some of the objections to free-flowing weirs are overcome. Existing structures, such as headgates, checks, and drops, can often be converted into measuring structures at a very small expense.

ORIFICES

Definitions.—Orifices were among the first means used for measuring flow. By definition an orifice is an opening, but the term is generally limited to openings in relatively thin walls. Under its broad meaning it

might include weir notches, nozzles, and even Venturi tubes. In this bulletin, it is restricted to rectangular or circular openings in thin walls, exclusive of weirs.

Free-flowing orifices are those discharging into air; that is, the downstream water surface is below the bottom of the orifice.

TABLE 7

RECOMMENDED SIZES AND DIMENSIONS FOR SUBMERGED-ORIFICE STRUCTURES*

Approximate range in capacity, cubic feet per second	Size of orifice			Height of structure, *B*, feet	Width of headwall, *A*, feet	Length, *E*, feet	Width, *W*, feet	Length of downstream wingwall, *C*, feet
	Height, *D*, inches	Length, *L*, inches	Area, square feet					
0.4 to 1.0	3	12	0.25	4.0	10.0	3.0	2.5	2.0
0.5 to 1.4	3	16	0.33	4.0	10.0	3.0	3.0	2.0
0.8 to 2.1	3	24	0.50	4.0	12.0	3.0	3.5	2.0
0.5 to 1.4	4	12	0.33	4.5	10.0	3.0	2.5	2.5
0.8 to 2.1	4	18	0.50	4.5	12.0	3.0	3.0	2.5
1.0 to 3.2	4	27	0.75	4.5	12.0	3.0	3.5	2.5
0.8 to 2.1	6	12	0.50	5.0	12.0	3.5	2.5	3.0
1.0 to 3.2	6	18	0.75	5.0	14.0	3.5	3.0	3.0
1.5 to 4.3	6	24	1.00	5.0	14.0	3.5	3.5	3.0
2.3 to 6.5	6	36	1.50	5.0	16.0	3.5	4.5	3.0
1.5 to 4.3	9	16	1.00	6.0	14.0	3.5	3.0	3.0
2.3 to 6.5	9	24	1.50	6.0	16.0	3.5	3.5	3.0
3.0 to 8.7	9	32	2.00	6.0	16.0	3.5	4.0	3.0

* Dimension letters shown in figure 10.

Submerged orifices are those discharging under water; that is, the downstream water surface is above the top of the orifice.

Partial submergence occurs when the downstream water surface is between the elevations of the top and bottom of the orifice. This condition is to be avoided.

The term *head* denotes the effective pressure producing flow through the orifice. For free-flowing orifices it is measured as the vertical distance from the upstream water surface to the center of the orifice. For submerged orifices it is the difference in elevation of the water surfaces on the two sides of the orifice.

The coefficient for an orifice is the ratio of the actual to the theoretical flow. For orifices in thin walls, with complete contractions, it is approximately 0.6; for partially suppressed contractions it may vary from 0.6 to nearly 1.0.

Complete contractions are secured when the orifice is in a smooth plate and its edges are sharp right angles not less than twice the least dimension of the orifice from the bottom and sides of the channel or any obstruction.

Types of Orifices Used for Measuring Water for Irrigation.—The principal types of orifices are (1) submerged orifices with fixed dimensions; (2) adjustable submerged orifices; (3) various kinds of miner's inch boxes; (4) calibrated commercial gates; and (5) thin-plate circular orifices in pipe lines. The last mentioned is discussed under the heading "Venturi meters and similar devices" in the second part.

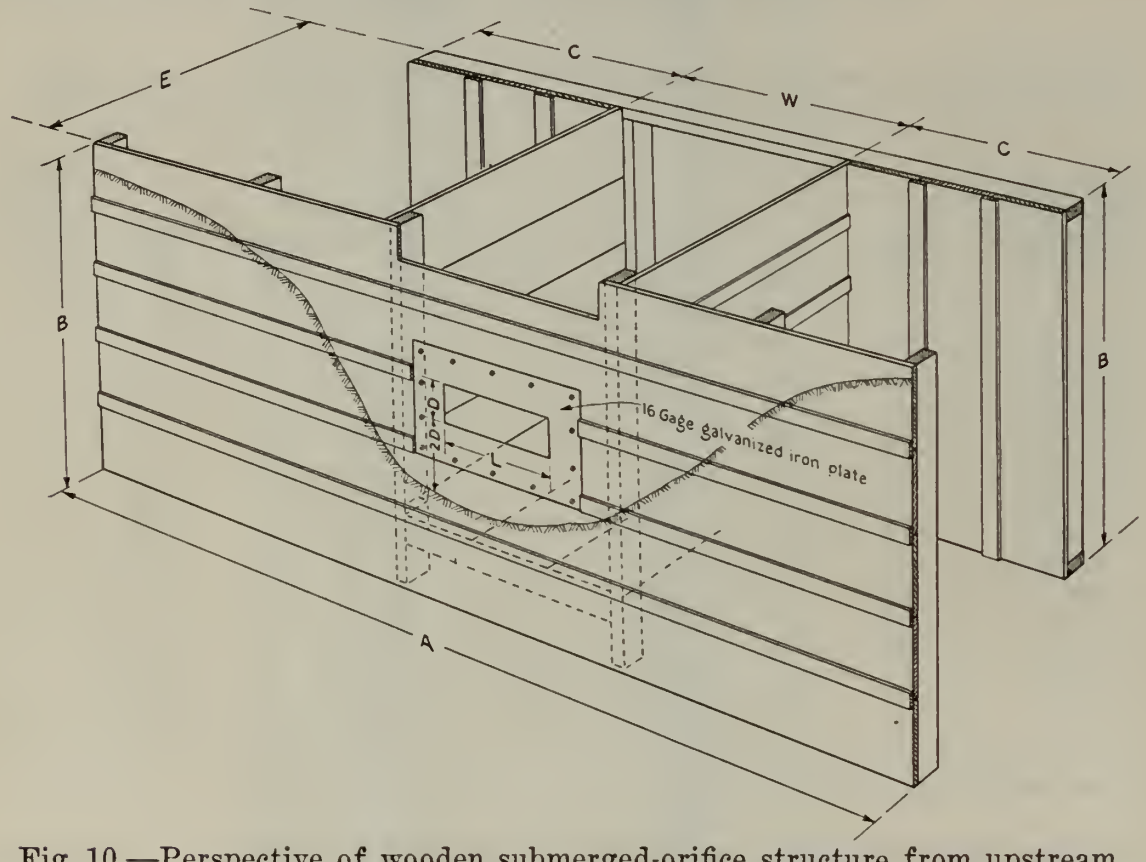


Fig. 10.—Perspective of wooden submerged-orifice structure from upstream.

Submerged Orifices with Fixed Dimensions.—These orifices are used where conditions are not satisfactory for weirs—mainly where the available head is insufficient. They are usually rectangular with the horizontal dimension from two to six times the height. They are generally installed in sufficiently large channels so that the contractions are complete, or very nearly so. The coefficient will then be approximately 0.61. For incomplete contractions, there is a lack of definite information regarding the coefficient.

Submerged-Orifice Structure.—Figure 10 shows a wooden submerged-orifice structure for which suggested dimensions are given in table 7. The larger sizes require additional framing members. The size of the orifice should be such that the flow can be measured with a head of 2 to 6 inches. Submerged orifices with fixed dimensions are not suitable for measuring streams in which the flow varies greatly. The structure shown allows for overflow in case of clogging or for excess water.

The essential features of a submerged-orifice structure are (1) a smooth vertical face of sufficient size; (2) an orifice with smooth, sharp

edges and of accurate dimensions; and (3) provision for measuring the head. Orifices may be readily constructed in flumes or lined ditches that are of sufficient size to insure complete contractions.

Use of Fixed-Dimension Submerged Orifices.—Since the head on a submerged orifice is the difference in elevation of the water surface upstream and downstream from the orifice, measurements are made at two points. Several methods are used. Gages may be fastened to the upstream

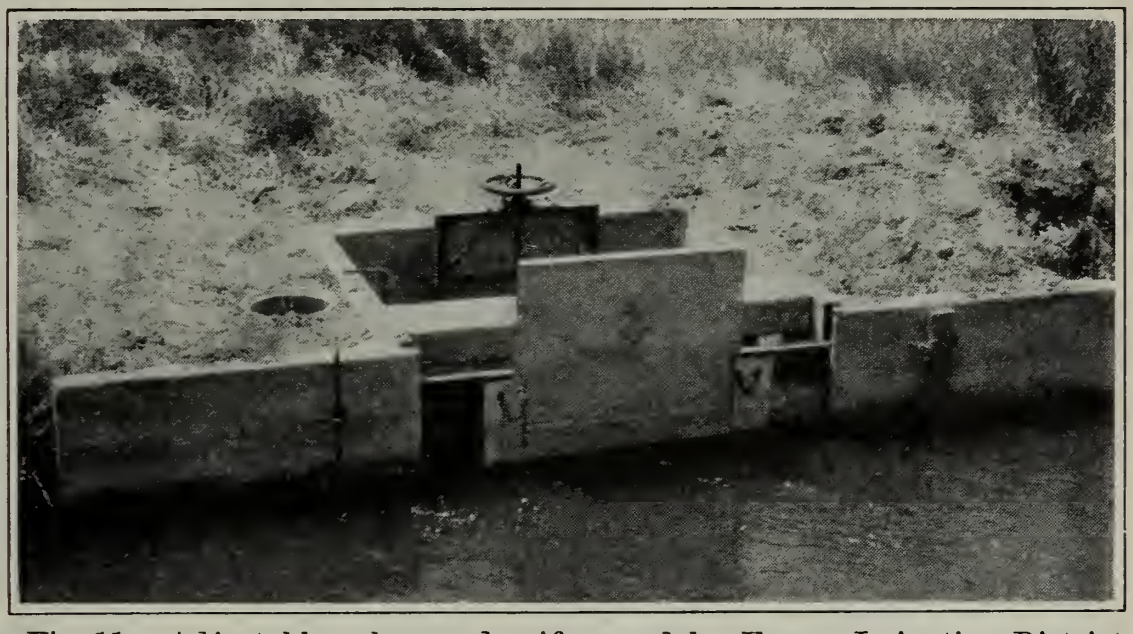


Fig. 11.—Adjustable submerged orifice used by Fresno Irrigation District. The orifice opening is adjustable in ½-square-foot increments from ½ square foot to 4 square feet.

and downstream wing walls. Often two stakes are set in the channel with the tops at the same elevation, one a few feet upstream from the orifice and the other a few feet downstream; and the distances from the tops of these stakes to the water surfaces are measured with a rule. The measurements should be made at points where the water surfaces are fairly quiet. A two-compartment measuring well of the type shown in figure 14 is desirable. The head is then measured as the difference in distances from the top of the partition to the two water surfaces.

The flow through fixed-dimension submerged orifices of various sizes is given in table 8, which is based upon a coefficient of 0.61.

Adjustable Submerged Orifices.—There are several kinds of adjustable submerged orifices. Some resemble submerged orifices with fixed dimensions except that their height is adjustable to accommodate a large range in flow without an excessive loss of head. These operate essentially the same as fixed-dimension orifices; and if the channel is sufficiently large to insure complete contraction for the maximum openings, the value of the coefficient should remain approximately constant and the same as for orifices with fixed dimensions. Table 8 may be used to determine the flow through orifices of this type.

TABLE 8

FLOW THROUGH RECTANGULAR SUBMERGED ORIFICES IN CUBIC FEET PER SECOND*

Head, H, in feet	Head, in inches, approx.	Cross-sectional area of orifice, A,						
		0.25 sq. ft.	0.333 sq. ft.	0.50 sq. ft.	0.75 sq. ft.	1.00 sq. ft.	1.50 sq. ft.	2.00 sq. ft.
		Flow in cubic feet per second						
0.01	1/8	0 122	0 163	0 245	0.367	0 489	0 73	0.98
0.02	1/4	0 173	0 230	0.346	0.518	0.691	1.04	1.38
0.03	3/8	0.212	0 282	0 424	0.635	0 847	1.27	1.69
0.04	1/2	0.245	0 326	0 489	0.734	0.978	1 47	1.96
0 05	5/8	0 273	0.364	0 547	0.820	1 09	1.64	2.19
0.06	3/4	0.300	0 399	0.599	0.899	1.20	1.80	2 40
0 07	13/16	0.324	0 431	0 647	0.971	1.29	1.94	2.59
0 08	15/16	0.346	0.461	0.691	1 04	1.38	2 07	2.77
0.09	1 1/16	0.367	0.489	0 734	1.10	1.47	2.20	2.94
0.10	1 3/16	0.387	0.518	0.773	1.16	1 56	2.32	3.09
0.11	1 5/16	0.406	0.540	0.811	1 22	1 62	2 43	3 24
0 12	1 7/16	0 424	0.564	0 847	1.27	1 69	2.54	3.39
0.13	1 9/16	0.441	0.587	0.882	1.32	1 76	2.65	3.53
0.14	1 11/16	0.458	0.609	0.915	1.37	1 83	2 75	3.66
0.15	1 13/16	0.474	0.631	0.947	1.42	1 90	2.84	3.79
0.16	1 15/16	0.489	0.651	0.978	1.47	1 96	2.93	3.91
0.17	2 1/16	0.504	0.671	1 01	1.51	2.02	3.02	4.03
0.18	2 3/16	0.519	0.691	1.04	1 56	2.08	3.11	4.15
0.19	2 1/4	0.533	0.710	1.07	1.60	2 13	3 20	4.26
0 20	2 3/8	0.547	0.729	1 09	1.64	2.19	3.28	4.38
0 21	2 1/2	0.561	0.746	1.12	1.68	2.24	3.36	4.48
0.22	2 5/8	0.574	0.765	1.15	1.72	2.30	3.46	4.59
0.23	2 3/4	0.587	0.781	1.17	1.76	2.35	3.52	4.69
0.24	2 7/8	0.600	0.798	1.20	1.80	2.40	3.60	4.79
0.25	3	0.612	0.815	1.22	1.83	2.45	3.67	4.89
0.26	3 1/8	0.624	0.831	1.25	1.87	2.49	3.74	4.99
0.27	3 1/4	0.636	0.846	1.27	1.91	2.54	3.81	5.08
0.28	3 3/8	0.646	0.862	1.29	1.94	2.59	3.88	5.18
0.29	3 1/2	0.659	0.878	1.32	1.98	2.64	3.96	5.28
0.30	3 5/8	0.670	0.892	1.34	2.01	2.68	4.02	5.36
0.31	3 3/4	0.681	0.908	1.36	2.05	2.73	4.09	5.45
0.32	3 13/16	0.692	0.920	1.38	2.07	2.76	4.15	5.53
0.33	3 15/16	0.703	0.936	1.41	2.11	2.81	4.22	5.62
0.34	4 1/16	0.713	0.950	1.43	2.14	2.85	4.28	5.70
0.35	4 3/16	0.724	0.963	1.45	2.17	2.89	4.34	5.78
0.36	4 5/16	0.734	0.976	1.47	2.20	2.93	4.40	5.87
0.37	4 7/16	0.745	0.991	1.49	2.23	2.98	4.46	5.95
0.38	4 9/16	0.754	1.00	1.51	2.26	3.02	4.52	6.03
0.39	4 11/16	0.764	1.02	1.53	2.29	3.05	4.58	6.11
0.40	4 13/16	0.774	1.03	1.55	2.32	3.09	4.64	6.19

* Computed from the formula $Q = 0.61\ A\ \sqrt{2\ g\ H}$.

TABLE 8—FLOW THROUGH RECTANGULAR SUBMERGED ORIFICES—(*Concluded*)

Head, *H*, in feet	Head, in inches, approx.	Cross-sectional area of orifice, *A*,						
		0.25 sq. ft.	0.333 sq. ft.	0.50 sq. ft.	0.75 sq. ft.	1.00 sq. ft.	1.50 sq. ft.	2.00 sq. ft.
		Flow in cubic feet per second						
0.41	4 15/16	0.783	1.04	1.57	2.35	3.13	4.70	6.27
0.42	5 1/16	0.792	1.06	1.59	2.38	3.17	4.75	6.34
0.43	5 3/16	0.802	1.07	1.60	2.41	3.21	4.81	6.42
0.44	5 1/4	0.811	1.08	1.62	2.43	3.24	4.87	6.49
0.45	5 3/8	0.820	1.09	1.64	2.46	3.28	4.92	6.56
0.46	5 1/2	0.829	1.10	1.66	2.49	3.32	4.98	6.64
0.47	5 5/8	0 839	1.12	1.68	2.52	3.36	5.04	6.71
0.48	5 3/4	0.847	1.13	1.70	2.54	3.39	5.08	6.78
0.49	5 7/8	0.856	1.14	1.71	2.57	3.42	5.14	6.85
0.50	6	0.865	1.15	1.73	2.59	3 46	5.19	6.92
0.51	6 1/8	0.873	1.16	1.75	2.62	3.49	5.24	6.99
0.52	6 1/4	0.882	1.17	1.76	2.65	3.53	5.29	7.05
0.53	6 3/8	0 890	1.19	1.78	2.67	3.56	5.34	7.12
0.54	6 1/2	0.898	1.20	1.80	2.70	3.59	5.39	7.19
0.55	6 5/8	0.907	1.21	1.81	2.72	3.63	5.44	7.25
0.56	6 3/4	0.915	1.22	1.83	2.75	3.66	5.49	7.32
0.57	6 13/16	0.923	1.23	1.85	2.77	3.69	5.54	7.38
0.58	6 15/16	0.931	1.24	1.86	2.79	3.73	5.59	7.45
0.59	7 1/16	0.939	1.25	1.88	2.82	3.76	5.64	7 51
0.60	7 3/16	0.947	1.26	1.90	2.84	3.79	5.68	7.58
0.61	7 5/16	0.955	1.27	1.91	2.87	3.82	5.73	7.64
0.62	7 7/16	0.963	1.28	1.93	2.89	3.85	5.78	7.70
0.63	7 9/16	0.971	1.29	1.94	2.91	3.88	5.82	7.76
0.64	7 11/16	0.978	1.30	1.96	2.93	3.91	5.87	7.82
0.65	7 13/16	0.986	1.31	1.97	2 96	3.94	5.92	7.89
0.66	7 15/16	0.993	1.32	1.99	2.98	3.97	5.96	7.95
0.67	8 1/16	1.00	1.33	2.00	3.00	4.00	6.01	8.01
0.68	8 3/16	1.01	1.34	2.02	3.02	4.03	6.05	8.06
0.69	8 1/4	1.02	1.35	2.03	3.05	4.06	6.10	8 13
0.70	8 3/8	1.02	1.36	2.05	3.07	4.09	6.14	8.18
0.71	8 1/2	1.03	1.37	2.06	3.09	4.12	6.19	8.25
0.72	8 5/8	1.04	1.38	2.08	3.11	4.15	6.23	8.30
0.73	8 3/4	1.05	1.39	2.09	3.14	4.18	6.27	8.36
0.74	8 7/8	1.05	1.40	2.10	3.16	4.21	6.31	8.42
0.75	9	1.06	1.41	2.12	3.18	4.24	6.36	8.48
0.76	9 1/8	1.07	1.42	2.13	3.20	4.26	6.40	8.53
0.77	9 1/4	1.07	1.43	2.15	3.22	4.29	6.43	8.58
0.78	9 3/8	1.08	1.44	2.16	3.24	4.32	6.48	8.64
0.79	9 1/2	1.09	1.45	2.17	3.26	4.35	6.52	8.70
0.80	9 5/8	1.09	1.46	2.19	3.28	4.38	6.56	8.75

For several years, Fresno Irrigation District has used orifices of the type shown in figure 11 for measuring deliveries to private ditches. They have proved less satisfactory than other devices, including calibrated gates and flow meters. According to tests conducted by the district, the coefficient ranges from 0.63 to 0.67.

Adjustable Submerged-Orifice Headgate.—The more usual type of adjustable submerged orifice is a combination headgate, or turnout, and measuring device. Such structures are usually made of wood and generally have either one or two slide gates that may be held open in any desired position by a bolt through a rising stem (fig. 12).

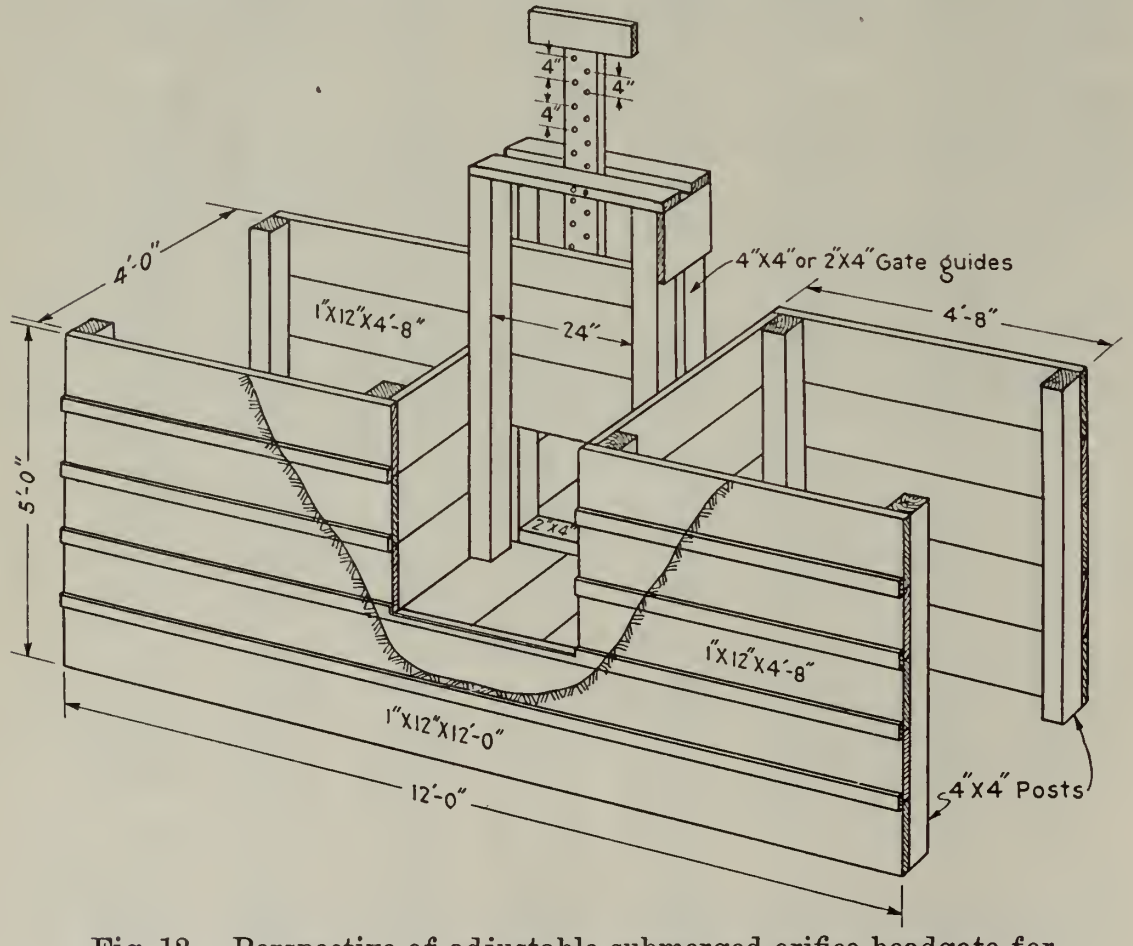


Fig. 12.—Perspective of adjustable submerged orifice headgate for which the flow curves are given in figure 13.

Submerged-orifice headgates are not accurate measuring devices. Being, however, convenient and inexpensive, they have been used extensively, although in many irrigation districts of California they are gradually being replaced by circular cast-iron gates with pipe outlets, or by concrete structures.

The effect of the velocity of the water approaching the orifice, known as the velocity of approach, is ordinarily neglected in using orifices; but to insure complete contraction, the distance from the sides and bottom of the channel to the edges of the orifice should be about twice the least dimension of the orifice. The cross-sectional area of the water prism

upstream from the orifice will then be about six times the area of the orifice, so that the effect of the velocity of approach will be negligible.

Since this condition seldom exists with an adjustable submerged-orifice headgate, the velocity of approach will have a relatively greater effect. Because it varies independently of either the gate opening or head, a correction is impractical; and, when it is neglected, a larger coefficient must be used to obtain the correct flow.

As previously stated, the coefficient for a thin-plate orifice with complete contractions is approximately 0.61 and is nearly independent of the head or of the area of the orifice, provided the velocity of approach is negligible. For orifices in which the contractions are completely suppressed, the coefficient is approximately 0.98; and for the adjustable submerged-orifice headgate with partial suppression it will sometimes exceed 1.0 because of the velocity of approach. In this case, however, the coefficient is not constant, since the conditions affecting the contractions change as the gate is opened. With the gate sill constructed as in figure 12, the direction of the current through the orifice is inclined upward for very small openings, and little contraction is produced by the bottom edge of the gate and the sill. The coefficient is high and increases as the front edge of the sill becomes rounded with wear. For medium gate openings the contractions are a maximum and the coefficient is a minimum. For large gate openings the contractions decrease, and the relatively higher velocities of approach again increase the coefficient.

Tests by Wadsworth[8] on the type of structure illustrated in figure 12 showed the coefficient to be a minimum of about 0.65 for gate openings of 1 to 1½ square feet and heads greater than half a foot, and a maximum of about 1.3 for gate openings of 2 square feet or more and heads of only 0.02 foot.

The flow through structures of the type shown in figure 12 with 4×4 inch gate guides and for similar structures with 2×4 inch gate guides laid flat against the wall is given in figure 13. These diagrams correct approximately for the variations in the coefficient under different conditions. No dependence should be placed upon measurements with heads less than 0.1 foot, especially for gate openings exceeding 1.5 square feet.

The reader is cautioned against using these graphs with structures built differently from those shown in figure 12. If possible, such structures should be calibrated in place or checked occasionally by independent measurements.

Standard wooden delivery gates are used as adjustable submerged orifices in Imperial Irrigation District to measure the water delivered to the farms. The structures used differ somewhat from the one shown

[8] Wadsworth, H. A. Unpublished report, 1922.

in figure 12, the principal difference—as far as it affects the accuracy of the structure for measuring water—being in the design of slide gate and gate sill. The slide gate, made from 1-inch lumber, rests on a sill or grade board consisting of a 2×4 or a 2×6 inch timber placed permanently on edge in the groove between the gate guides.

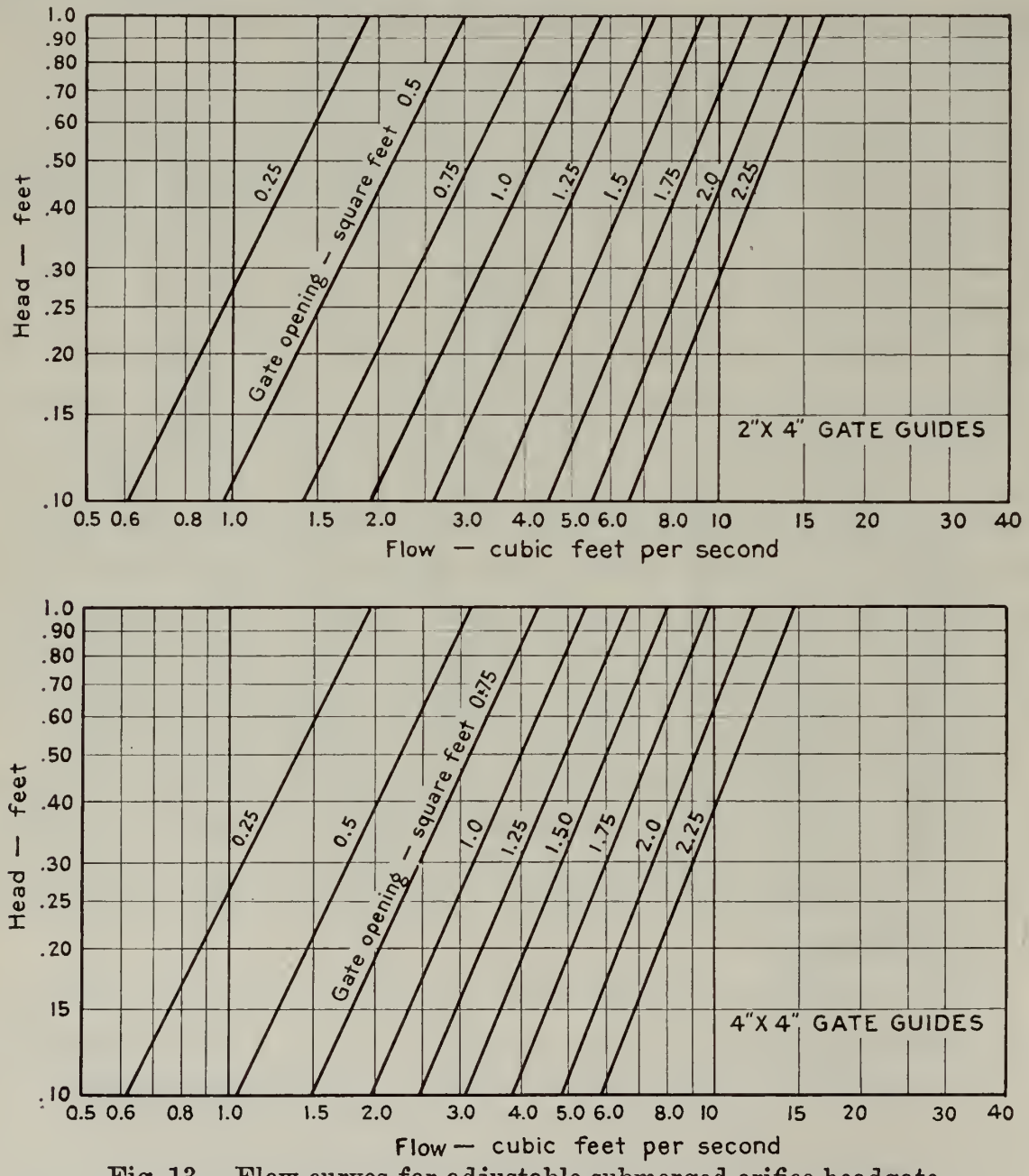


Fig. 13.—Flow curves for adjustable submerged orifice headgate shown in figure 12.

This construction increases the contraction and tends to stabilize the value of the coefficient. The discharge tables used with these gates are based on a coefficient of 0.622, which is lower than the values found by Wadsworth. The District admits that measurements with this type of orifice are at least 10 per cent low.

Calibrated Commercial Gates (Calco Metergate).—An outstanding development during the past decade has been the calibration of commercial gates for water measurement.

The first known experimental work of this kind was done by Modesto Irrigation District in 1927.[9] Recognizing that the circular cast-iron turnout gates might be used for measuring deliveries to small laterals and farm ditches, this district conducted tests to determine, for different gate openings, the over-all loss of head through the gates and the attached short length of concrete pipe extending through the ditch bank.

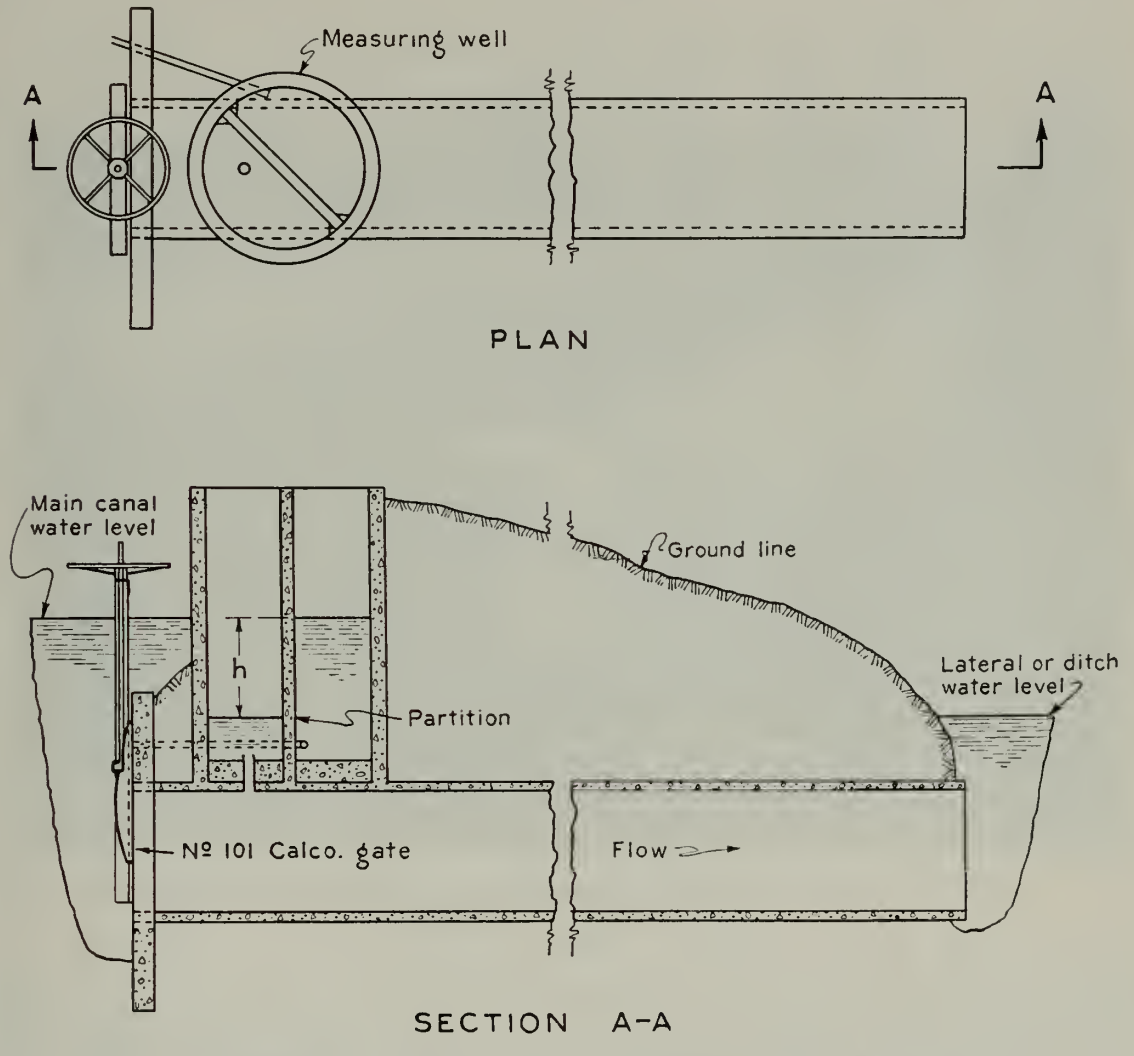


Fig. 14.—Plan and longitudinal section of Metergate as installed in Fresno Irrigation District.

As expected, a consistent relation was found to exist between the gate opening, the total loss of head, and the discharge. Tests were conducted on gates ranging from 12 to 36 inches in diameter, and curves and tables were prepared giving the flow in cubic feet per second for different gate openings measured on the rising stem. The head as determined is the difference in elevation of the water surfaces in the supply canal and the outlet ditch. Gages are placed on the upstream and downstream headwalls of the turnout structure, and the head is taken as the difference in the reading of the two gages. The discharge tables, printed on

[9] Holmes, W. H. Flow of water through gates and short pipe sections. Western Construction News 2:52. July 25, 1927.

convenient cards, are carried by the ditch-tenders when making and regulating deliveries.

Fresno Irrigation District found that, for its conditions, the arrangement used by the Modesto district was not entirely suitable, principally because of the varying lengths of pipe required. In addition, many of the gates in use were smaller than those calibrated at Modesto. The Fresno

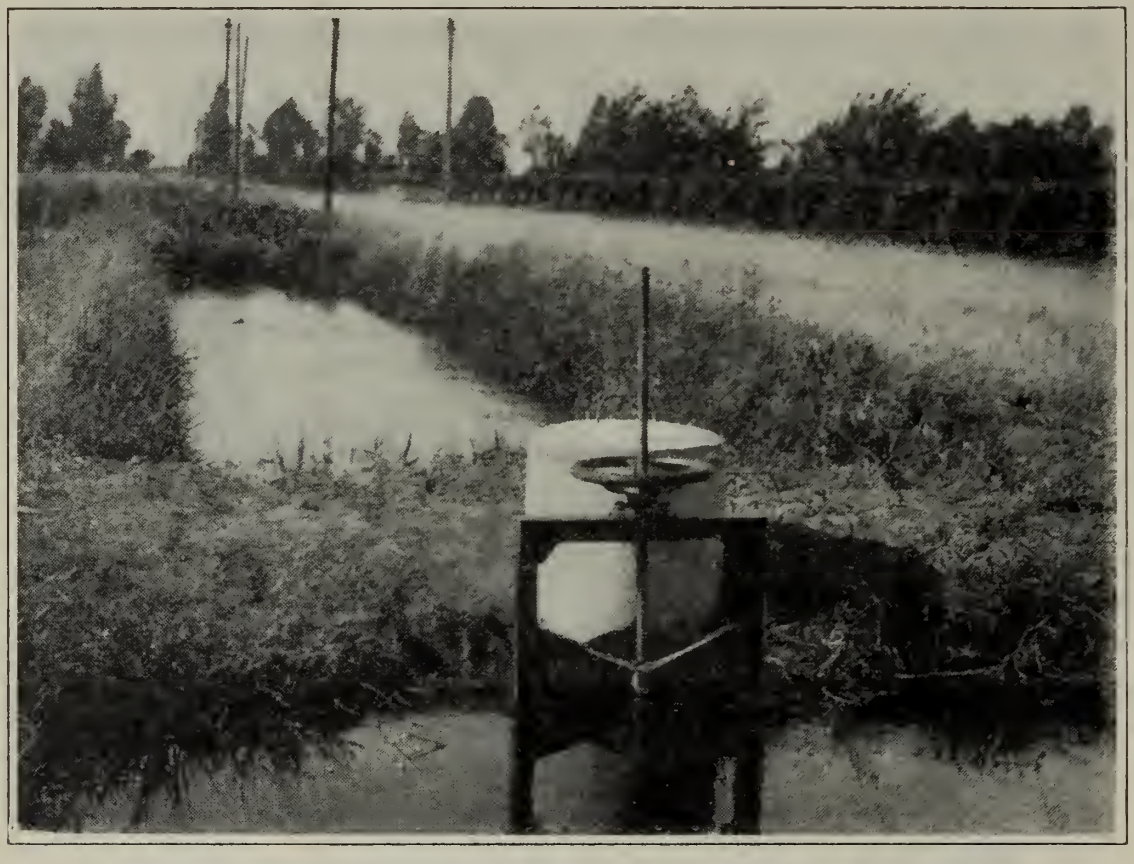


Fig. 15.—Calco Metergate for measuring irrigation deliveries in Fresno Irrigation District.

district decided, therefore, to calibrate the gates for loss of head through the gate only, thus making their use as a measuring device independent of the length of pipe attached. An installation involving the use of an auxiliary measuring well was adopted. Between July, 1927, and May, 1928, approximately 1,100 tests were made on gates from 8 to 24 inches in diameter, under very favorable conditions in a field laboratory in the district. The results were published in 1928[10] as a report containing both graphs and tables for flow through gates from 8 to 24 inches in diameter.

The standard installation for a turnout structure in Fresno Irrigation District, using the calibrated gate, now known as the Calco Metergate,

[10] Fresno Irrigation District. Methods and devices used in the measurement and regulation of flow to service ditches, together with tables for field use. 39 pages. Fresno Irrigation District, Fresno, California, 1928. Reprints are available from Fresno Irrigation District or from the manufacturer of the gates. The latter also has tables covering gates up to 42 inches in diameter.

is shown in figure 14. In this instance, concrete pipe is used for the outlet through the bank and also for the measuring well. Figure 15 shows this gate in use. Later tests by the Fresno district and the manufacturer showed the same tables to be applicable for installations using corrugated iron culvert pipe instead of concrete pipe. The manufacturer has also developed an all-metal measuring well for use with the gate and has extended the flow tables to cover gates up to 42 inches in diameter.

Miner's-Inch Measurement.—The California statute inch of $\frac{1}{40}$ cubic foot per second is the flow through an orifice with an area of 1 square inch under a head of 6 inches above the center of the orifice if the coefficient is 0.635. The southern California inch, or flow through an orifice 1 inch square under a head of 4 inches, is equal to $\frac{1}{50}$ cubic foot per second if the coefficient is 0.622. In localities where the miner's inch is commonly used, the water is generally measured by means of "inch boxes," the essential part of which is a free-flowing orifice. When the proper head is maintained, the number of miner's inches is equal to the area of the orifice in square inches.

Many ingenious "inch boxes" have been devised, most of them containing an orifice plate with adjustable opening and some auxiliary means of regulating or maintaining the required pressure head. The accuracy of a measurement through any of these structures depends primarily upon (1) the accuracy with which the pressure head can be regulated or maintained, (2) the ratio of head to height of orifice, (3) the velocity of approach, (4) the conditions affecting the contraction of the jet, (5) the accuracy with which the area of the orifice can be determined, and (6) freedom from submergence.

To maintain an exact pressure head on an orifice is difficult. In an effort to do this, the means generally employed is either a regulating gate of some type adjustable to any desired opening, or a spill crest at the desired level allowing excess water to flow over. By the first method the flow can be regulated accurately at any time, but no provision is made for fluctuations in the flow between the times of regulation. In the second method, the water must rise above the desired level, thus introducing a small error. Some of the miner's-inch structures in use employ both principles.

Because of the difficulty in accurately regulating the pressure head and the frequent need of correcting flows measured under other heads, table 9 has been prepared. The correct flow for any head may be determined by multiplying the area of the orifice by the factor given in the table.

For accurate measurements with free-flowing orifices, the height of the orifice should not be greater than the head used. Accordingly, ori-

fices for measuring southern California miner's inches should be not more than 4 inches high; and those for measuring California statute miner's inches, not more than 6 inches.

The velocity of approach seldom produces an appreciable error. With complete contraction it is usually negligible.

TABLE 9

FACTORS TO BE USED FOR MAKING CORRECTIONS FOR FLOW MEASURED THROUGH MINER'S-INCH ORIFICES UNDER VARYING PRESSURE HEADS

Pressure head above center of orifice		Factors to be multiplied by area of orifice in square inches	
Inches	Feet	For southern California miner's inches (1/50 cu. ft. per sec.)	California statute miner's inches (1/40 cu. ft. per sec.)
3	0.250	0.85	0.71
3¼	0.271	0.90	0.73
3½	0.292	0.94	0.76
3¾	0.312	0.97	0.79
4	0 333	1.00	0.82
4¼	0.354	1.03	0.84
4½	0 375	1.06	0.87
4¾	0.396	1.09	0.89
5	0.417	1.12	0.91
5¼	0.437	1.15	0.94
5½	0.458	1.18	0.96
5¾	0.479	1.20	0.98
6	0.500	1.22	1.00
6¼	0.521	1.25	1.02
6½	0.542	1.28	1.04
6¾	0.562	1.30	1.06
7	0.583	1.32	1.08
7¼	0.604	1.35	1.10
7½	0.625	1.37	1.12
7¾	0.646	1.39	1.14
8	0.667	1.41	1.16

To insure complete contraction, the upstream face of the orifice plate should be smooth and free from obstructions for a distance twice the least dimension of the orifice from its nearest edge. The edges should be smooth and sharp; and if the plate is more than ¼ inch thick, they should be beveled on the downstream face. Obviously, these conditions cannot be entirely satisfied with "inch" plates containing adjustable slides on the upstream face; and the flow through such orifices is always high, although the error may not be great enough to make them undesirable. When the slides are on the lower side of the plate, some leakage generally occurs.

In measuring the area of the opening of adjustable orifices, small errors are frequently made. If the width of such an opening, which is 4

inches high, is adjusted or measured to the nearest ⅛ of an inch, the error in the area may be as high as 5 per cent for small openings.

Accurate measurements cannot be made through a miner's-inch plate if the water level on the downstream face of the plate rises above the lower edge of the orifice. The jet must be free-flowing; that is, air must circulate underneath it at all times. For this reason, inch plates must sometimes be installed in high stands—an expensive arrangement, objectionable for several reasons.

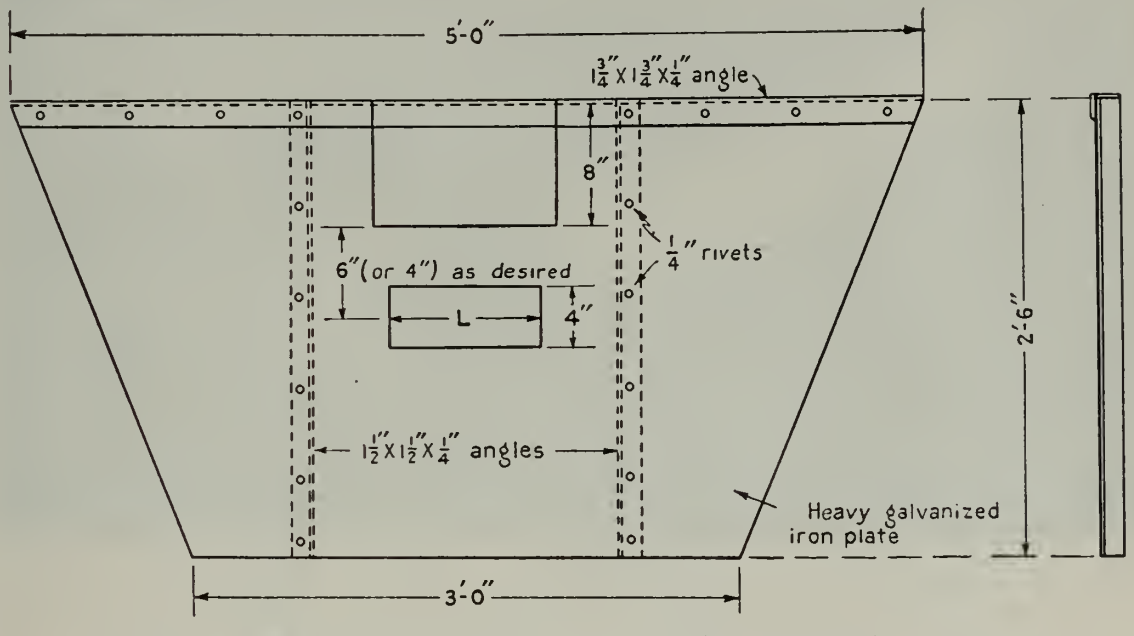


Fig. 16.—Metal miner's-inch plate with fixed-dimension orifice.

Fixed-Dimension Orifice Inch Plate.—A very simple type of miner's-inch measuring structure (figure 16), used in the foothill section of San Joaquin Valley, consists of a metal plate with a fixed-dimension orifice 4 inches high and sufficiently wide to give the flow the user is entitled to receive. A weir notch is cut in the plate with the crest 4 or 6 inches above the center of the orifice. The plate is set across the ditch a short distance below the delivery gate, which is adjusted so that the water surface is held at the level of the weir crest. Because of the weir notch, more water can be delivered when available; and the crest is a convenient datum by which to adjust the water level. Having no obstructions on the face of the plate, this device will measure a definite flow rather accurately; but it is not convenient for either larger or smaller flows.

Riverside Box.—In the device used on the canal of the Riverside Water Company, at Riverside (fig. 17), the water enters through the bottom of the box and is measured out through an adjustable cast-iron measuring plate in the end. The orifice is 5 inches high and 14 inches wide and is equipped with two sliding gates making the opening adjustable for areas up to 70 square inches. The top of the plate is 4 inches

Fig. 17.—Riverside miner's-inch box. (From Cir. 250.)

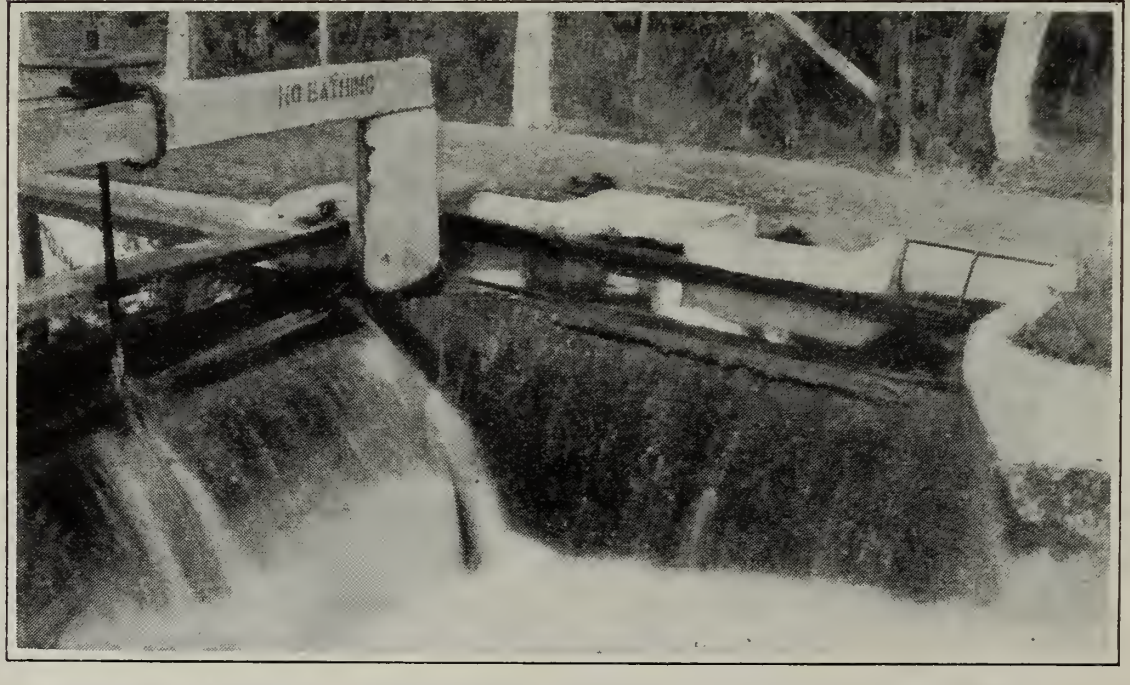


Fig. 18.—Anaheim miner's-inch box with two adjustable orifice plates.

above the center of the orifice. When the slides are adjusted so that the water level is at the top of the plate, the area of the opening is equivalent to the discharge in southern California miner's inches. The plate con-

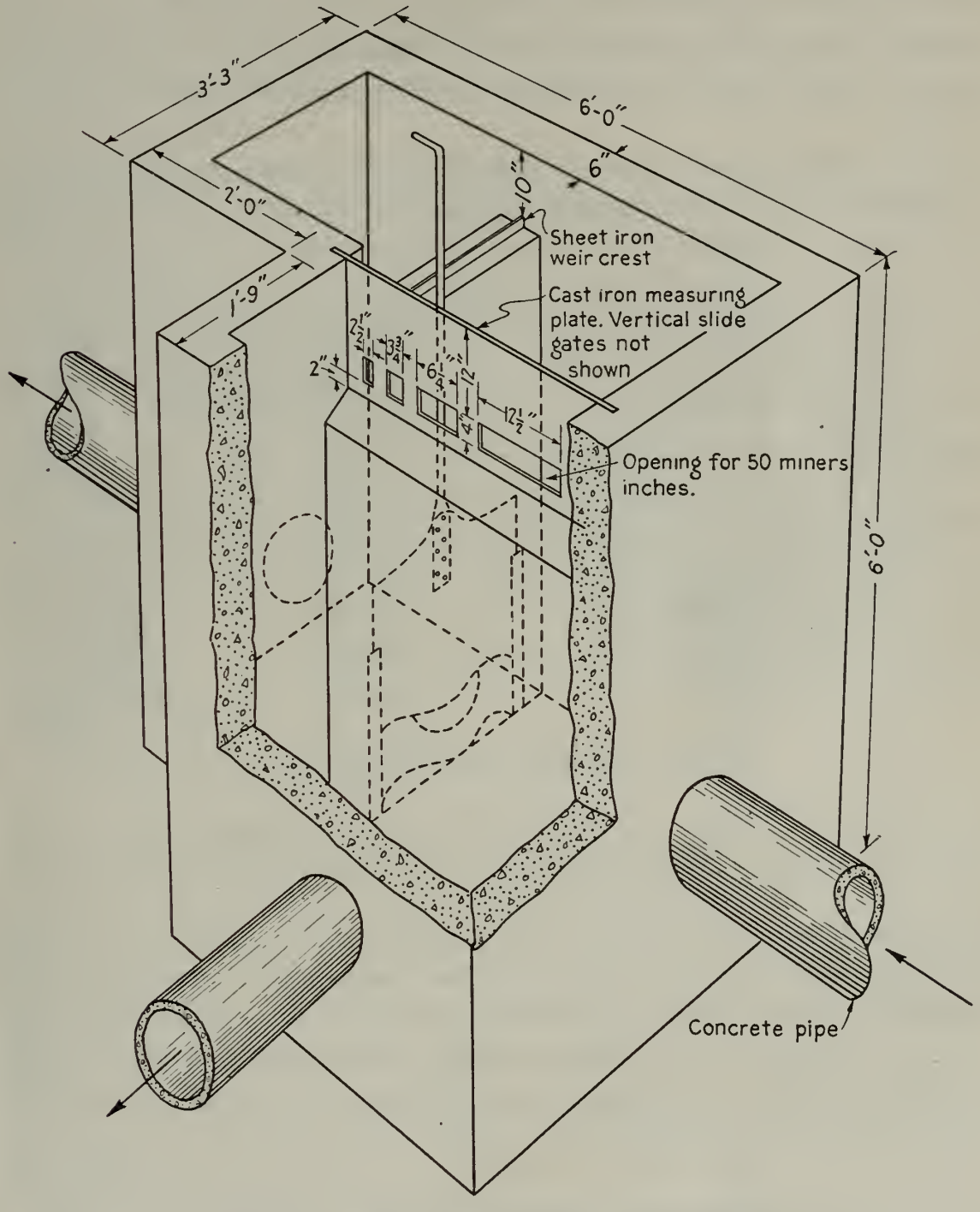


Fig. 19.—Azusa miner's-inch box or hydrant.

tains graduation marks 1 inch apart to assist in measuring the opening. After passing through the orifice, the water usually flows into a concrete pipe line.

Anaheim Measuring Box.—The measuring box of the Anaheim Union Water Company, at Anaheim (fig. 18), is designed to divert and measure a definite amount of water from the company's canal to the user's ditch or pipe line. It consists of a by-pass into which water can be diverted

from the main canal, an adjustable miner's-inch plate, and an overflow crest so set that any excess water diverted from the main canal pours back into the canal below the check gate. The measuring plate is installed so that the center of the orifice is 4 inches below the crest of the overflow. The plate is so designed and installed that the contractions are largely suppressed, so that an error in measurement results in favor of the user.

Azusa Miner's-Inch Box or Hydrant.—The Azusa miner's-inch box or hydrant (fig. 19) is designed to divert and measure part of the flow

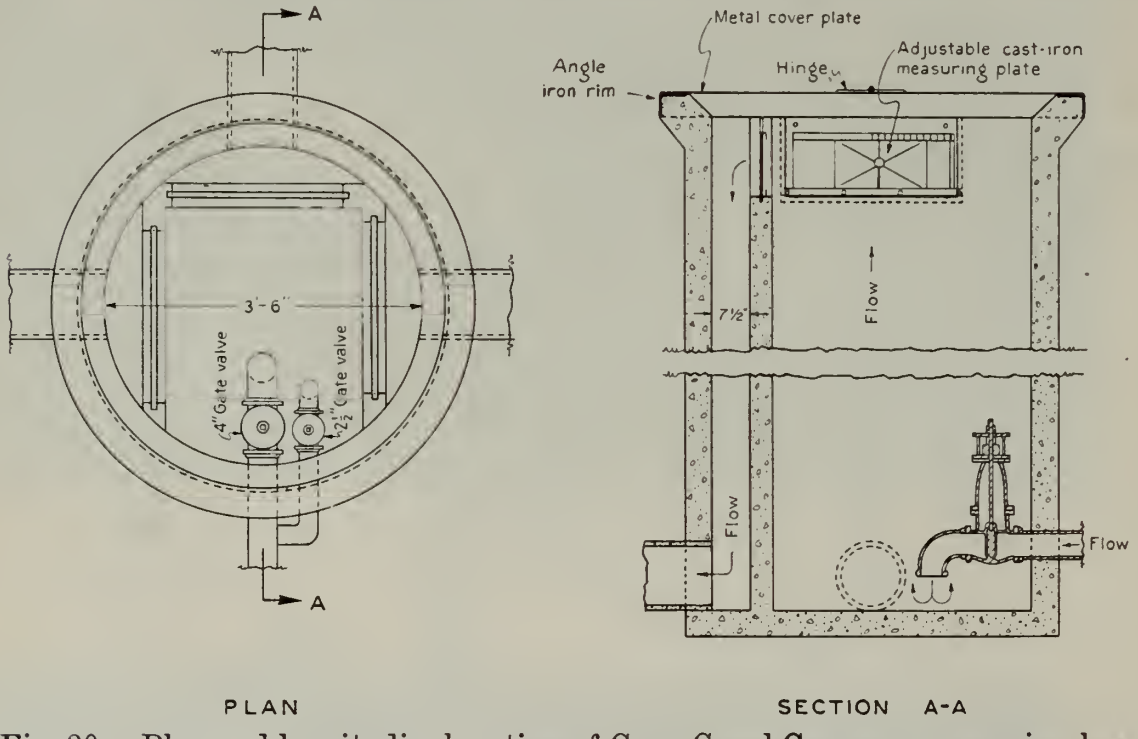


Fig. 20.—Plan and longitudinal section of Gage Canal Company measuring box.

from one pipe line to another. It is used by the Azusa Water Company, at Azusa. The structure, a concrete box built over the main pipe line, contains a cast-iron inch plate with four orifices, each equipped with a vertical slide gate. The orifices are all 4 inches high and 2½, 3¾, 6¼, and 12½ inches wide, giving areas of 10, 15, 25, and 50 square inches, respectively. By using different combinations of orifices, amounts up to 100 miner's inches can be measured. The water level is adjusted to the level of the spill crest 4 inches above the center of the orifice by means of a gate partition wall under the spill crest.

According to tests in the outdoor hydraulic laboratory of the Division of Irrigation Investigations and Practice, at Davis, the flow through the orifices in southern California miner's inches is slightly more than their area in square inches; but the error was smaller than for any of the other adjustable orifices tested.

Gage Canal Company Measuring Box.—The structure used by the Gage Canal Company at Riverside (fig. 20) is a stand pipe built of

42-inch concrete pipe with from one to three measuring plates, designed to divert and measure water from the company's high-pressure lines to the user's low-pressure lines. Water enters through a 4-inch iron pipe equipped with a gate valve inside the stand and is deflected downward by an elbow against the bottom so that the energy due to the high velocity is absorbed.

Cast-iron adjustable measuring plates, with a maximum capacity of 60 miner's inches, are set in 3-inch concrete partition walls. Each orifice is 6 inches high and 10 inches wide and is equipped on the upstream side with a horizontal slide gate that can be clamped in any desired position. The plate has twelve graduations, each representing 5 square inches, to aid in measuring the area. The gate valve is adjusted to hold the water level at a mark on the upstream face of the plate 4 inches above the center of the orifice. The structure is covered with a steel plate, hinged at the center and so arranged that it can be locked down.

Tests at Davis on a measuring plate of this type, installed under similar conditions, showed the flow through the orifice to be about 10 per cent high. The explanation is that the contractions are suppressed by the gate guides, by the concrete wall in which the plate is set, and by the small distance of only 1 inch from the water level to the top of the orifice.

PARSHALL MEASURING FLUME

The Parshall measuring flume, formerly known as the improved Venturi flume, was recently developed by the United States Department of Agriculture, coöperating with the Colorado Agricultural Experiment Station in search of a more satisfactory device for measuring water in open channels. The experimental work in developing and calibrating this flume was conducted by Ralph L. Parshall, chiefly at the Colorado Agricultural Experiment Station at Fort Collins.

The first device in this development, known as the Venturi flume, was reported by Cone[11] in 1917. Having apparent practical advantages, it was further studied.[12]

Because of certain drawbacks, changes in the design of the structure were made. The device as finally developed was called the improved Venturi flume.[13] After study and tests by the Division of Water Rights of the California State Department of Public Works, it was adopted and recommended as a standard measuring device for use in California. At the suggestion of the Special Committee on Irrigation Hydraulics of

[11] Cone, V. M. The Venturi flume. Jour. Agr. Research 9:115–130. 1917.

[12] Parshall, Ralph L., and Carl Rohwer. The Venturi flume. Colorado Agr. Exp. Sta. Bul. 265:1–28. 1921.

[13] Parshall, Ralph L. The improved Venturi flume. Colorado Agr. Exp. Sta. Bul. 336:1–84. 1928.

the American Society of Civil Engineers, the name was later officially changed to *Parshall measuring flume* to avoid confusion with the Venturi meter and to give credit to the engineer chiefly responsible for its development.

Advantages and Limitations.—The accuracy of the Parshall measuring flume is within limits that are allowable in irrigation practice—ordinarily within 5 per cent. Flumes ranging from 3 inches to 10 feet in throat width can accommodate flows of from $\frac{1}{30}$ cubic foot per second to 200 cubic feet per second. Much larger flumes now in use have proved satisfactory. The plane surfaces make construction easy.

The Parshall measuring flume will operate successfully with a loss of head less than that required for weirs. Only a single head need be measured for "free-flow" conditions, which exist when the head at the lower gage is less than about 60 per cent of that of the upper gage. When the head at the lower gage is greater than this, the upper gage reading is affected, and submerged flow results. Fairly accurate measurements can be made with a submergence of 95 per cent provided the heads are determined at both places.

Because the velocity through the structure is higher than that in the channel, silt will not deposit in the structure where it would affect the accuracy. Ordinary velocities of approach have little or no affect on the measurement. The flume may be used with recording or registering instruments when continuous records are wanted, or with an indicating gage graduated to give the flow in any unit desired.

Like most water-measuring devices, the Parshall flume has certain limitations. It cannot readily be combined with a turnout. It is more expensive and more difficult to build than a weir or submerged orifice. Only the smallest sizes are portable. For free-flow conditions the exit velocity is relatively high, and channel protection downstream from the flume is generally necessary to prevent erosion.

Use of the Parshall Measuring Flume.—Water is measured through the Parshall flume in much the same manner as over a weir. Free-flow is determined from a measurement of the head at the upper gage by use of table 10. For submerged flow the head must be measured at both the upper and lower gages, and an amount determined from figure 21 must be subtracted from the flow given in table 10 to obtain the correct flow. The correction for larger flumes is obtained by multiplying the correction for the 1-foot flume (fig. 21) by the factor given in table 11.

For example, suppose that for a 2-foot flume the upper head, H_a, is 1.6 feet and the lower head, H_b, is 1.2 feet. The ratio is therefore $\frac{1.2}{1.6} = 0.75$, or 75 per cent submergence; and a correction is required.

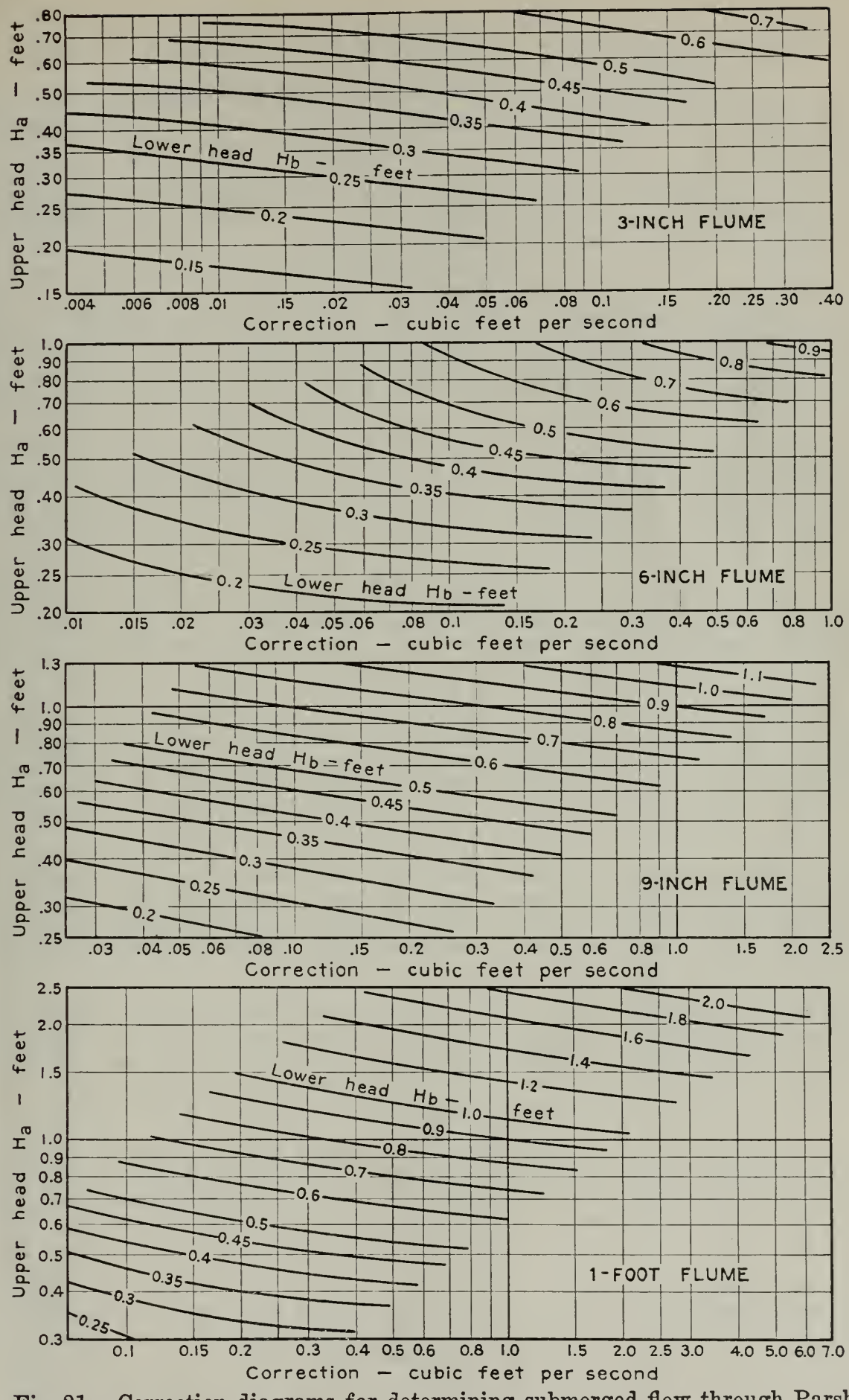


Fig. 21.—Correction diagrams for determining submerged flow through Parshall measuring flumes. Subtract the amount obtained from this diagram from table 10 for the same upper head, H_a. For larger flumes, use diagram for the 1-foot flume and multiply correction by the factor given in table 11.

TABLE 10

FREE-FLOW THROUGH PARSHALL MEASURING FLUMES*†

Upper head, H_a		Throat width											
Feet	Inches (approx.)	3 inches	6 inches	9 inches	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	10 feet
		Flow in cubic feet per second											
0.10	1 3/16	0.028	0.05	0.09	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.11	1 5/16	0.033	0.06	0.10	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.12	1 7/16	0.037	0.07	0.12	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.13	1 9/16	0.042	0.08	0.14	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.14	1 11/16	0.047	0.09	0.15	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.15	1 13/16	0.053	0.10	0.17	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.16	1 15/16	0.058	0.11	0.19	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.17	2 1/16	0.064	0.12	0.20	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.18	2 3/16	0.070	0.14	0.22	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.19	2 1/4	0.076	0.15	0.24	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.20	2 3/8	0.082	0.16	0.26	0.35	0.66	0.97	1.26	.....	.....	.....	.....	.....
0.21	2 1/2	0.089	0.18	0.28	0.37	0.71	1.04	1.36	.....	.....	.....	.....	.....
0.22	2 5/8	0.095	0.19	0.30	0.40	0.77	1.12	1.47	.....	.....	.....	.....	.....
0.23	2 3/4	0.102	0.20	0.32	0.43	0.82	1.20	1.58	.....	.....	.....	.....	.....
0.24	2 7/8	0.109	0.22	0.35	0.46	0.88	1.28	1.69	.....	.....	.....	.....	.....
0.25	3	0.117	0.23	0.37	0.49	0.93	1.37	1.80	2.22	2.63	.....	.....	.....
0.26	3 1/8	0.124	0.25	0.39	0.51	0.99	1.46	1.91	2.36	2.80	.....	.....	.....
0.27	3 1/4	0.131	0.26	0.41	0.54	1.05	1.55	2.03	2.50	2.97	.....	.....	.....
0.28	3 3/8	0.138	0.28	0.44	0.58	1.11	1.64	2.15	2.65	3.15	.....	.....	.....
0.29	3 1/2	0.146	0.29	0.46	0.61	1.18	1.73	2.27	2.80	3.33	.....	.....	.....
0.30	3 5/8	0.154	0.31	0.49	0.64	1.24	1.82	2 39	2.96	3.52	4.08	4.62	.....
0.31	3 3/4	0.162	0.32	0.51	0.68	1.30	1.92	2.52	3.12	3.71	4.30	4.88	.....
0.32	3 13/16	0.170	0.34	0.54	0.71	1.37	2.02	2.65	3.28	3.90	4.52	5.13	.....
0.33	3 15/16	0.179	0.36	0.56	0.74	1.44	2.12	2.78	3.44	4.10	4.75	5.39	.....
0.34	4 1/16	0.187	0.38	0.59	0.77	1.50	2.22	2.92	3.61	4.30	4.98	5.66	.....
0.35	4 3/16	0.196	0.39	0.62	0.80	1.57	2.32	3.06	3.78	4.50	5.22	5.93	.....
0.36	4 5/16	0.205	0.41	0.64	0.84	1.64	2.42	3.19	3.95	4.71	5.46	6.20	.....
0.37	4 7/16	0.213	0.43	0.67	0.88	1.72	2.53	3.34	4.13	4.92	5.70	6.48	.....
0.38	4 9/16	0.222	0.45	0.70	0.92	1.79	2.64	3.48	4.31	5.13	5.95	6.76	.....
0.39	4 11/16	0.231	0.47	0.73	0.95	1.86	2.75	3.62	4.49	5.35	6.20	7.05	.....
0.40	4 13/16	0.241	0.48	0.76	0.99	1.93	2.86	3.77	4.68	5.57	6.46	7.34	9.1
0.41	4 15/16	0.250	0.50	0.78	1.03	2.01	2.97	3.92	4.86	5.80	6.72	7.64	9.5
0.42	5 1/16	0.260	0.52	0.81	1.07	2.09	3.08	4.07	5.05	6.02	6.98	7.94	9.8
0.43	5 3/16	0.269	0.54	0.84	1.11	2.16	3.20	4.22	5.24	6.25	7.25	8.24	10.2
0.44	5 1/4	0.279	0.56	0.87	1.15	2.24	3.32	4.38	5.43	6.48	7.52	8.55	10.6
0.45	5 3/8	0.289	0.58	0.90	1.19	2.32	3.44	4.54	5.63	6.72	7.80	8.87	11.0
0.46	5 1/2	0.299	0.61	0.94	1.23	2.40	3.56	4.70	5.83	6.96	8.08	9.19	11.4
0.47	5 5/8	0.309	0.63	0.97	1.27	2.48	3.68	4.86	6.03	7.20	8.36	9.51	11.8
0.48	5 3/4	0.319	0.65	1.00	1.31	2.57	3.80	5.03	6.24	7.44	8.65	9.8	12.2
0.49	5 7/8	0.329	0.67	1.03	1.35	2.65	3.92	5.20	6.45	7.69	8.94	10.2	12.6

*Parshall, R. L. The improved Venturi flume. Colorado Agr. Exp. Sta. Bul. **336**:19-23. 1928.

† Parshall, R. L. Measuring water in irrigation channels. U. S. Dept. Agr. Farmer's Bul. **1683**:10-11. 1932.

TABLE 10—FLOW THROUGH PARSHALL MEASURING FLUMES—(*Continued*)

Upper head, H_a		Throat width											
Feet	Inches (approx.)	3 inches	6 inches	9 inches	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	10 feet
		Flow in cubic feet per second											
0.50	6	0.339	0.69	1.06	1.39	2.73	4.05	5.36	6.66	7.94	9.23	10.5	13.1
0.51	6 1/8	0.350	0.71	1.10	1.44	2.82	4.18	5.53	6.87	8.20	9.53	10.9	13.5
0.52	6 1/4	0.361	0.73	1.13	1.48	2.90	4.31	5.70	7.09	8.46	9.83	11.2	13.9
0.53	6 3/8	0.371	0.76	1.16	1.52	2.99	4.44	5.88	7.30	8.72	10.1	11.5	14.3
0.54	6 1/2	0.382	0.78	1.20	1.57	3.08	4.57	6.05	7.52	8.98	10.5	11.9	14.8
0.55	6 5/8	0.393	0.80	1.23	1.62	3.17	4.70	6.23	7.74	9.25	10.8	12.2	15.2
0.56	6 3/4	0.404	0.82	1.26	1.66	3.26	4.84	6.41	7.97	9.52	11.1	12.6	15.7
0.57	6 13/16	0.415	0.85	1.30	1.70	3.35	4.98	6.59	8.20	9.79	11.4	13.0	16.1
0.58	6 15/16	0.427	0.87	1.33	1.75	3.44	5.11	6.77	8.43	10.1	11.7	13.3	16.6
0.59	7 1/16	0.438	0.89	1.37	1.80	3.53	5.25	6.96	8.66	10.4	12.0	13.7	17.1
0.60	7 3/16	0.450	0.92	1.40	1.84	3.62	5.39	7.15	8.89	10.6	12.4	14.1	17.5
0.61	7 5/16	0.462	0.94	1.44	1.88	3.72	5.53	7.34	9.13	10.9	12.7	14.5	18.0
0.62	7 7/16	0.474	0.97	1.48	1.93	3.81	5.68	7.53	9.37	11.2	13.0	14.8	18.5
0.63	7 9/16	0.485	0.99	1.51	1.98	3.91	5.82	7.72	9.61	11.5	13.4	15.2	19.0
0.64	7 11/16	0.497	1.02	1.55	2.03	4.01	5.97	7.91	9.85	11.8	13.7	15.6	19.5
0.65	7 13/16	0.509	1.04	1.59	2.08	4.11	6.12	8.11	10.1	12.1	14.1	16.0	19.9
0.66	7 15/16	0.522	1.07	1.63	2.13	4.20	6.26	8.31	10.3	12.4	14.4	16.4	20.4
0.67	8 1/16	0.534	1.10	1.66	2.18	4.30	6.41	8.51	10.6	12.7	14.8	16.8	20.9
0.68	8 3/16	0.546	1.12	1.70	2.23	4.40	6.56	8.71	10.9	13.0	15.1	17.2	21.5
0.69	8 1/4	0.558	1.15	1.74	2.28	4.50	6.71	8.91	11.1	13.3	15.5	17.6	22.0
0.70	8 3/8	0.571	1.17	1.78	2.33	4.60	6.86	9.11	11.4	13.6	15.8	18.0	22.5
0.71	8 1/2	0.584	1.20	1.82	2.38	4.70	7.02	9.32	11.6	13.9	16.2	18.5	23.0
0.72	8 5/8	0.597	1.23	1.86	2.43	4.81	7.17	9.53	11.9	14.2	16.6	18.9	23.5
0.73	8 3/4	0.610	1.26	1.90	2.48	4.91	7.33	9.74	12.1	14.5	16.9	19.3	24.1
0.74	8 7/8	0.623	1.28	1.94	2.53	5.02	7.49	9.95	12.4	14.9	17.3	19.7	24.6
0.75	9	.....	1.31	1.98	2.58	5.12	7.65	10.2	12.7	15.2	17.7	20.1	25.1
0.76	9 1/8	.....	1.34	2.02	2.63	5.23	7.81	10 4	12.9	15.5	18.0	20.6	25.7
0.77	9 1/4	.....	1.36	2.06	2.68	5.34	7.97	10.6	13.2	15.8	18.4	21.0	26.2
0.78	9 3/8	.....	1.39	2.10	2.74	5.44	8.13	10 8	13.5	16.2	18.8	21.5	26.8
0.79	9 1/2	.....	1.42	2 14	2.80	5.55	8.30	11.0	13.8	16.5	19.2	21.9	27.3
0.80	9 5/8	.....	1.45	2.18	2.85	5.66	8.46	11.3	14.0	16.8	19.6	22.4	27.9
0.81	9 3/4	.....	1.48	2.22	2.90	5.77	8.63	11.5	14.3	17.2	20.0	22.8	28.5
0.82	9 13/16	.....	1.50	2.27	2.96	5.88	8.79	11.7	14.6	17.5	20.4	23.3	29.0
0.83	9 15/16	.....	1.53	2.31	3.02	6.00	8.96	11.9	14.9	17.8	20.8	23.7	29.6
0.84	10 1/16	.....	1.56	2.35	3.07	6.11	9.13	12.2	15.2	18.2	21.2	24.2	30.2
0.85	10 3/16	.....	1.59	2.39	3.12	6.22	9.30	12.4	15.5	18.5	21.6	24.6	30.8
0.86	10 5/16	.....	1.62	2.44	3.18	6.33	9.48	12.6	15.8	18.9	22.0	25.1	31.4
0.87	10 7/16	.....	1.65	2.48	3.24	6.44	9.65	12.8	16.0	19.2	22.4	25.6	31.9
0.88	10 9/16	.....	1.68	2.52	3.29	6.56	9.82	13.1	16.3	19.6	22.8	26.1	32.5
0.89	10 11/16	.....	1.71	2.57	3.35	6.68	10.0	13.3	16.6	19.9	23 2	26.5	33.1

TABLE 10—FLOW THROUGH PARSHALL MEASURING FLUMES—(*Continued*)

Upper head, H_a		Throat width											
Feet	Inches (approx.)	3 inches	6 inches	9 inches	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	10 feet
		Flow in cubic feet per second											
0 90	10 13/16	.....	1.74	2.61	3.41	6.80	10.2	13.6	16.9	20.3	23.7	27.0	33.7
0.91	10 15/16	.....	1.77	2.66	3.46	6.92	10.4	13.8	17.2	20.7	24.1	27.5	34.4
0.92	11 1/16	.....	1.81	2.70	3.52	7.03	10.5	14.0	17.5	21.0	24.5	28.0	35.0
0.93	11 3/16	.....	1.84	2.75	3.58	7.15	10.7	14.3	17.8	21.4	24.9	28.5	35.6
0.94	11 1/4	.....	1.87	2.79	3.64	7.27	10.9	14.5	18.1	21.8	25.4	29.0	36.2
0.95	11 3/8	.....	1.90	2.84	3.70	7.39	11.1	14.8	18.4	22.1	25.8	29.5	36 8
0.96	11 1/2	.....	1.93	2.88	3.76	7.51	11.3	15.0	18.8	22.5	26.2	30.0	37.5
0.97	11 5/8	.....	1.97	2.93	3.82	7.63	11.4	15 3	19.1	22.9	26.7	30.5	38.1
0.98	11 3/4	.....	2.00	2.98	3.88	7.75	11.6	15.5	19.4	23.2	27.1	31.0	38.7
0.99	11 7/8	.....	2.03	3.02	3.94	7.88	11.8	15.8	19.7	23.6	27.6	31.5	39.4
1.00	12	.....	2 06	3.07	4.00	8.00	12.0	16.0	20.0	24.0	28.0	32.0	40.0
1.01	12 1/8	.....	2.09	3.12	4.06	8.12	12.2	16.3	20.3	24.4	28.4	32.5	40.7
1.02	12 1/4	.....	2.12	3.17	4.12	8.25	12.4	16.5	20.6	24.8	28.9	33.0	41.3
1.03	12 3/8	.....	2.16	3.21	4.18	8.38	12.6	16.8	21.0	25.2	29.4	33.6	42.0
1.04	12 1/2	.....	2.19	3.26	4.25	8.50	12.8	17.0	21.3	25.6	29.8	34.1	42.6
1.05	12 5/8	.....	2.22	3.31	4.31	8.63	13.0	17.3	21.6	25.9	30.3	34.6	43.3
1.06	12 3/4	.....	2.26	3.36	4.37	8.76	13.2	17.5	21.9	26.3	30.7	35.1	44.0
1.07	12 13/16	.....	2.29	3.40	4.43	8.88	13.3	17.8	22.3	26.7	31.2	35.7	44.6
1.08	12 15/16	.....	2.32	3.45	4.50	9.01	13.5	18.1	22.6	27.1	31.7	36.2	45.3
1.09	13 1/16	.....	2.36	3.50	4.56	9.14	13.7	18.3	22.9	27.5	32.1	36.8	46.0
1.10	13 3/16	.....	2.40	3.55	4.62	9.27	13.9	18.6	23.3	27.9	32.6	37.3	46 7
1.11	13 5/16	.....	2.43	3.60	4 68	9.40	14.1	18.9	23.6	28.4	33.1	37.8	47.4
1.12	13 7/16	.....	2.46	3.65	4.75	9.54	14.3	19 1	23.9	28.8	33.6	38.4	48.0
1.13	13 9/16	.....	2.50	3.70	4.82	9.67	14.5	19.4	24.3	29.2	34.1	38.9	48.7
1.14	13 11/16	.....	2.53	3.75	4.88	9.80	14.7	19.7	24.6	29.6	34.5	39.5	49.4
1.15	13 13/16	.....	2.57	3.80	4.94	9.94	14.9	19.9	25.0	30.0	35.0	40.1	50.1
1.16	13 15/16	.....	2.60	3.85	5.01	10.1	15.1	20.2	25.3	30.4	35.5	40.6	50.8
1.17	14 1/16	.....	2.64	3.90	5.08	10.2	15.3	20.5	25.7	30.8	36.0	41.2	51.6
1.18	14 3/16	.....	2.68	3.95	5.15	10.3	15.6	20.8	26.0	31.3	36.5	41.8	52.3
1.19	14 1/4	.....	2.71	4.01	5.21	10.5	15.8	21.1	26.4	31.7	37.0	42.3	53.0
1.20	14 3/8	.....	2.75	4.06	5.28	10 6	16.0	21.3	26.7	32.1	37.5	42.9	53.7
1.21	14 1/2	.....	2.78	4.11	5.34	10.8	16.2	21.6	27.1	32.5	38.0	43.5	54.4
1.22	14 5/8	.....	2.82	4.16	5.41	10.9	16.4	21.9	27.4	33.0	38.5	44.1	55.2
1.23	14 3/4	.....	2.86	4.22	5.48	11.0	16.6	22.2	27.8	33.4	39.0	44.6	55.9
1.24	14 7/8	.....	2.89	4.27	5.55	11.2	16.8	22.5	28.1	33.8	39.5	45.2	56.6
1.25	15	.....	.....	4.32	5.62	11.3	17.0	22.8	28.5	34.3	40.0	45.8	57.4
1.26	15 1/8	.....	.....	4.37	5.69	11.5	17.2	23.0	28.9	34.7	40.5	46.4	58.1
1.27	15 1/4	.....	.....	4.43	5.76	11.6	17.4	23.3	29.2	35.1	41.1	47.0	58.9
1.28	15 3/8	.....	.....	4.48	5.82	11.7	17.7	23.6	29.6	35.6	41.6	47.6	59.6
1.29	15 1/2	.....	.....	4.53	5.89	11.9	17.9	23.9	30.0	36.0	42.1	48.2	60.4

TABLE 10—FLOW THROUGH PARSHALL MEASURING FLUMES—(*Continued*)

Upper head, H_a		Throat width											
Feet	Inches (approx.)	3 inches	6 inches	9 inches	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	10 feet
		Flow in cubic feet per second											
1.30	15 5/8	.....	.....	4.59	5.96	12.0	18.1	24.2	30.3	36.5	42.6	48.8	61.1
1.31	15 3/4	.....	.....	4.64	6.03	12.2	18.3	24.5	30.7	36.9	43.1	49.4	61.9
1.32	15 11/16	.....	.....	4.69	6.10	12.3	18.5	24.8	31.1	37.4	43.7	50.0	62.7
1.33	15 15/16	.....	.....	4.75	6.18	12.4	18.8	25.1	31.4	37.8	44.2	50.6	63.4
1.34	16 1/16	.....	.....	4.80	6.25	12.6	19.0	25.4	31.8	38.3	44.7	51.2	64.2
1.35	16 3/16	.....	.....	4.86	6.32	12.7	19.2	25.7	32.2	38.7	45.3	51 8	65.0
1.36	16 5/16	.....	.....	4.92	6.39	12.9	19.4	26.0	32.6	39.2	45.8	52.5	65.7
1.37	16 7/16	.....	.....	4.97	6.46	13.0	19.6	26.3	33.0	39.7	46.4	53.1	66.5
1.38	16 9/16	.....	.....	5.03	6.53	13.2	19.9	26.6	33.3	40.1	46.9	53.7	67.3
1.39	16 11/16	.....	.....	5 08	6.60	13.3	20.1	26.9	33.7	40.6	47.4	54.3	68.1
1.40	16 13/16	.....	.....	.....	6.68	13.5	20.3	27.2	34.1	41.1	48.0	55.0	68.9
1.41	16 15/16	.....	.....	.....	6.75	13.6	20.6	27.5	34.5	41.5	48.5	55.6	69.7
1.42	17 1/16	.....	.....	.....	6.82	13.8	20.8	27.8	34.9	42.0	49.1	56.2	70.5
1.43	17 3/16	.....	.....	.....	6.89	13.9	21.0	28.1	35.3	42.5	49.6	56.9	71.3
1.44	17 1/4	.....	.....	.....	6.97	14.1	21.2	28.5	35.7	42.9	50.2	57.5	72.1
1 45	17 3/8	.....	.....	.....	7.04	14.2	21.3	28.8	36.1	43.4	50.8	58.1	72.9
1 46	17 1/2	.....	.....	.....	7.12	14.4	21.7	29.1	36.5	43.9	51.3	58.8	73.7
1.47	17 5/8	.....	.....	.....	7.19	14.5	21.9	29.4	36.9	44.4	51.9	59.4	74.6
1.48	17 3/4	.....	.....	.....	7.26	14.7	22.2	29.7	37.3	44.9	52.4	60.1	75.4
1.49	17 7/8	.....	.....	.....	7.34	14.9	22.4	30.0	37.7	45.3	53.0	60.7	76.2
1.50	18	.....	.....	.....	7.41	15.0	22.6	30.3	38.1	45.8	53.6	61.4	77.0
1.51	18 1/8	.....	.....	.....	7.49	15.2	22.9	30.7	38.5	46.3	54.2	62.1	77 9
1.52	18 1/4	.....	.....	.....	7.57	15.3	23.1	31.0	38.9	46.8	54.7	62.7	78.7
1.53	18 3/8	.....	.....	.....	7.64	15.5	23.4	31.3	39.3	47.3	55.3	63.4	79.5
1.54	18 1/2	.....	.....	.....	7.72	15.6	23.6	31.6	39.7	47.8	55.9	64.0	80.4
1.55	18 5/8	.....	.....	.....	7.80	15.8	23.8	32.0	40.1	48.3	56.5	64.7	81.2
1.56	18 3/4	.....	.....	.....	7.87	15.9	24.1	32.3	40.5	48.8	57.1	65.4	82.1
1 57	18 13/16	.....	.....	.....	7.95	16.1	24.3	32.6	40.9	49.3	57.7	66.1	82.9
1.58	18 15/16	.....	.....	.....	8.02	16.3	24.6	32.9	41.4	49.8	58.2	66.7	83.8
1.59	19 1/16	.....	.....	.....	8.10	16.4	24.8	33.3	41.8	50.3	58.8	67.4	84.6
1 60	19 3/16	.....	.....	.....	8.18	16.6	25 1	33.6	42.2	50.8	59.4	68.1	85.5
1.61	19 5/16	.....	.....	.....	8.26	16.7	25.3	33.9	42.6	51.3	60.0	68.8	86.4
1.62	19 7/16	.....	.....	.....	8.34	16.9	25.5	34.3	43.0	51.8	60.6	69.5	87.2
1.63	19 9/16	.....	.....	.....	8.42	17.1	25.8	34.6	43.4	52.3	61.2	70.2	88.1
1 64	19 11/16	.....	.....	.....	8.49	17.2	26.0	34.9	43.9	52.8	61.8	70.9	89.0
1.65	19 13/16	.....	.....	.....	8.57	17.4	26.3	35.3	44.3	53.3	62.4	71.6	89.9
1.66	19 15/16	.....	.....	.....	8.65	17.6	26.5	35.6	44.7	53.9	63.0	72.3	90.7
1.67	20 1/16	.....	.....	.....	8.73	17.7	26.8	35.9	45.1	54.4	63.6	73.0	91.6
1.68	20 1/16	.....	.....	.....	8 81	17.9	27.0	36.3	45.6	54.9	64.3	73.7	92.5
1.69	20 1/4	.....	.....	.....	8.89	18.0	27.3	36.6	46.0	55.4	64.9	74.4	93.4

TABLE 10—FLOW THROUGH PARSHALL MEASURING FLUMES—(*Continued*)

Upper head, H_a		Throat width											
Feet	Inches (approx.)	3 inches	6 inches	9 inches	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	10 feet
		Flow in cubic feet per second											
1.70	20 3/8	.....	.....	.....	8.97	18.2	27.6	37.0	46.4	56.0	65.5	75.1	94.3
1.71	20 1/2	.....	.....	.....	9.05	18.4	27.8	37.3	46.9	56.5	66.1	75.8	95.2
1.72	20 5/8	.....	.....	.....	9.13	18.5	28.1	37.7	47.3	57.0	66.7	76.5	96.1
1.73	20 3/4	.....	.....	.....	9.21	18.7	28.3	38.0	47.7	57.5	67.3	77.2	97.0
1.74	20 7/8	.....	.....	.....	9.29	18.9	28.6	38.3	48.2	58.1	68.0	77.9	97.9
1.75	21	.....	.....	.....	9.38	19.0	28.8	38.7	48.6	58.6	68.6	78.7	98.8
1.76	21 1/8	.....	.....	.....	9.46	19.2	29.1	39.0	49.1	59.1	69.2	79.4	99.7
1.77	21 1/4	.....	.....	.....	9.54	19.4	29.3	39.4	49.5	59.7	69.9	80.1	100.6
1.78	21 3/8	.....	.....	.....	9.62	19.6	29.6	39.7	49.9	60.2	70.5	80.8	101.5
1.79	21 1/2	.....	.....	.....	9.70	19.7	29.9	40.1	50.4	60.7	71.1	81.6	102.4
1.80	21 5/8	.....	.....	.....	9.79	19.9	30.1	40.5	50.8	61.3	71.8	82.3	103.4
1.81	21 3/4	.....	.....	.....	9.87	20.1	30.4	40.8	51.3	61.8	72.4	83.0	104.4
1.82	21 13/16	.....	.....	.....	9.95	20.2	30.7	41.2	51.7	62.4	73.0	83.8	105.3
1.83	21 15/16	.....	.....	.....	10.0	20.4	30.9	41.5	52.2	62.9	73.7	84.5	106.2
1.84	22 1/16	.....	.....	.....	10.1	20.6	31.2	41.9	52.6	63.5	74.3	85.3	107.1
1.85	22 3/16	.....	.....	.....	10.2	20.8	31.5	42.2	53.1	64.0	75.0	86.0	108.1
1.86	22 5/16	.....	.....	.....	10.3	20.9	31.7	42.6	53.6	64.6	75.6	86.8	109.0
1.87	22 7/16	.....	.....	.....	10.4	21.1	32.0	43.0	54.0	65.1	76.3	87.5	110.0
1.88	22 9/16	.....	.....	.....	10.5	21.3	32.3	43.3	54.5	65.7	76.9	88.3	110.9
1.89	22 11/16	.....	.....	.....	10.5	21.5	32.5	43.7	54.9	66.3	77.6	89.0	111.9
1.90	22 13/16	.....	.....	.....	10.6	21.6	32.8	44.1	55.4	66.8	78.2	89.8	112.9
1.91	22 15/16	.....	.....	.....	10.7	21.8	33.1	44.4	55.9	67.4	78.9	90.5	113.8
1.92	23 1/16	.....	.....	.....	10.8	22.0	33.3	44.8	56.3	67.9	79.6	91.3	114.8
1.93	23 3/16	.....	.....	.....	10.9	22.2	33.6	45.2	56.8	68.5	80.2	92.1	115.8
1.94	23 1/4	.....	.....	.....	11.0	22.4	33.9	45.5	57.3	69.1	80.9	92.8	116.7
1.95	23 3/8	.....	.....	.....	11.1	22.5	34.1	45.9	57.7	69.6	81.6	93.6	117.7
1.96	23 1/2	.....	.....	.....	11.1	22.7	34.4	46.3	58.2	70.2	82.2	94.4	118.7
1.97	23 5/8	.....	.....	.....	11.2	22.9	34.7	46.6	58.7	70.8	82.9	95.1	119.7
1.98	23 3/4	.....	.....	.....	11.3	23.1	35.0	47.0	59.1	71.4	83.6	95.9	120.6
1.99	23 7/8	.....	.....	.....	11.4	23.2	35.3	47.4	59.6	71.9	84.3	96.7	121.6
2.00	24	.....	.....	.....	11.5	23.4	35.5	47.8	60.1	72.5	84.9	97.5	122.6
2.01	24 1/8	.....	.....	.....	11.6	23.6	35.8	48.1	60.6	73.1	85.6	98.3	123.6
2.02	24 1/4	.....	.....	.....	11.7	23.8	36.1	48.5	61.0	73.7	86.3	99.1	124.6
2.03	24 3/8	.....	.....	.....	11.8	24.0	36.4	48.9	61.5	74.2	87.0	99.8	125.6
2.04	24 1/2	.....	.....	.....	11.8	24.2	36.7	49.3	62.0	74.8	87.7	100.6	126.6
2.05	24 5/8	.....	.....	.....	11.9	24.3	36.9	49.7	62.5	75.4	88.4	101.4	127.6
2.06	24 3/4	.....	.....	.....	12.0	24.5	37.2	50.1	63.0	76.0	89.1	102.2	128.6
2.07	24 13/16	.....	.....	.....	12.1	24.7	37.5	50.4	63.5	76.6	89.8	103.0	129.6
2.08	24 15/16	.....	.....	.....	12.2	24.9	37.8	50.8	63.9	77.2	90.4	103.8	130.6
2.09	25 1/16	.....	.....	.....	12.3	25.1	38.1	51.2	64.4	77.8	91.1	104.6	131.6

TABLE 10—FLOW THROUGH PARSHALL MEASURING FLUMES—(*Concluded*)

Upper head, H_a		Throat width											
Feet	Inches (approx.)	3 inches	6 inches	9 inches	1 foot	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet	10 feet
		Flow in cubic feet per second											
2.10	25 3/16	.....	.....	.....	12.4	25.3	38.4	51.6	64.9	78.4	91.8	105.4	132.7
2.11	25 5/16	.....	.....	.....	12.5	25.5	38.6	52.0	65.4	79.0	92.5	106.2	133.7
2.12	25 7/16	.....	.....	.....	12.6	25.6	38.9	52.4	65.9	79 6	93.3	107.0	134.7
2.13	25 9/16	.....	.....	.....	12.6	25.8	39.2	52.8	66.4	80.2	94.0	107 9	135.7
2.14	25 11/16	.....	.....	.....	12.7	26.0	39.5	53.2	66.9	80.8	94.7	108.7	136.8
2.15	25 13/16	.....	.....	.....	12.8	26.2	39.8	53.5	67.4	81.4	95.4	109.5	137.8
2.16	25 15/16	.....	.....	.....	12.9	26.4	40.1	53.9	67.9	82.0	96.1	110.3	138.8
2.17	26 1/16	.....	.....	.....	13.0	26.6	40.4	54.3	68.4	82.6	96.8	111.1	139.9
2.18	26 3/16	.....	.....	.....	13.1	26.8	40.7	54.7	68.9	83.2	97.5	111.9	140.9
2.19	26 1/4	.....	.....	.....	13.2	27.0	41.0	55.1	69.4	83.8	98.2	112.8	142.0
2.20	26 3/8	.....	.....	.....	13.3	27.2	41.3	55.5	69.9	84.4	98.9	113.6	143.0
2.21	26 1/2	.....	.....	.....	13.4	27.3	41.5	55.9	70.4	85.0	99.7	114.4	144.1
2.22	26 5/8	.....	.....	.....	13.5	27.5	41.8	56.3	70.9	85.6	100.0	115.3	145.1
2.23	26 3/4	.....	.....	.....	13.6	27.7	42.1	56.7	71.4	86.3	101.1	116 1	146.2
2.24	26 7/8	.....	.....	.....	13.7	27.9	42.4	57.1	71.9	86.9	101.8	116.9	147.3
2.25	27	.....	.....	.....	13.7	28.1	42.7	57.5	72.4	87.5	102.6	117.8	148.3
2.26	27 1/8	.....	.....	.....	13 8	28.3	43.0	57.9	72.9	88.1	103.3	118.6	149.4
2.27	27 1/4	.....	.....	.....	13.9	28.5	43.3	58.3	73.5	88.7	104.0	119.5	150.5
2.28	27 3/8	.....	.....	.....	14.0	28.7	43.6	58.7	74.0	89.4	104.8	120.3	151.5
2.29	27 1/2	.....	.....	.....	14.1	28.9	43.9	59.2	74.5	90.0	105.5	121.2	152.6
2.30	27 5/8	.....	.....	.....	14.2	29.1	44.2	59.6	75.0	90.6	106.2	122.0	153.7
2.31	27 3/4	.....	.....	.....	14.3	29.3	44.5	60.0	75.5	91.2	107.0	122.9	154.8
2.32	27 13/16	.....	.....	.....	14.4	29.5	44.8	60.4	76.0	91.9	107.7	123.7	155.8
2.33	27 15/16	.....	.....	.....	14.5	29.7	45.1	60.8	76.6	92.5	108.5	124.6	156.9
2.34	28 1/16	.....	.....	.....	14.6	29.9	45.4	61.2	77.1	93.1	109.2	125.4	158.0
2.35	28 3/16	.....	.....	.....	14.7	30.1	45.7	61.6	77.6	93.8	110.0	126.3	159.1
2.36	28 5/16	.....	.....	.....	14.8	30.3	46.0	62.0	78.1	94.4	110.7	127.2	160.2
2.37	28 7/16	.....	.....	.....	14.9	30.5	46.4	62.4	78.7	95.1	111.5	128.0	161.3
2.38	28 9/16	.....	.....	.....	15.0	30.7	46.7	62.9	79.2	95.7	112.2	128.9	162.4
2.39	28 11/16	.....	.....	.....	15.1	30.9	47.0	63.3	79.7	96.3	113.0	129.8	163.5
2.40	28 13/16	.....	.....	.....	15.2	31.1	47.3	63.7	80.3	97.0	113.7	130.7	164.6
2.41	28 15/16	.....	.....	.....	15.3	31.3	47.6	64.1	80.8	97.6	114.5	131.5	165.7
2.42	29 1/16	.....	.....	.....	15.4	31.5	47.9	64.5	81.3	98.3	115.3	132.4	166.8
2.43	29 3/16	.....	.....	.....	15.5	31.7	48.2	65.0	81.8	98.9	116.0	133.3	167.9
2.44	29 1/4	.....	.....	.....	15.6	31.9	48.5	65.4	82.4	99.6	116.8	134.2	169.1
2.45	29 3/8	.....	.....	.....	15.6	32.1	48.8	65.8	82.9	100 2	117.6	135.1	170.2
2.46	29 1/2	.....	.....	.....	15.7	32.3	49.1	66.2	83.5	100.9	118.3	135.9	171.3
2.47	29 5/8	.....	.....	.....	15.9	32.5	49.5	66.7	84.0	101.5	119.1	136.8	172.4
2.48	29 3/4	.....	.....	.....	15.9	32.7	49.8	67.1	84.5	102.2	119.9	137.7	173.6
2.49	29 7/8	.....	.....	.....	16.0	32.9	50.1	67.5	85.1	102.8	120.6	138.6	174.7
2.50	30	.....	.....	.....	16.1	33.1	50.4	67.9	85.6	103.5	121.4	139.5	175.8

One need not compute the percentage of submergence, except to determine whether a correction is necessary—a question often answered by inspection. On the left margin of the diagram, figure 21, for a 1-foot flume, take a point about one-fifth of the distance between the lines for $H_a = 1.5$ and 2.0, respectively, and follow horizontally to the right until this imaginary line intersects the curved line for $H_b = 1.2$. Then follow an imaginary vertical line downward to the bottom of the diagram and read the correction, which is approximately 0.5 cubic feet per

TABLE 11

FACTORS "*M*" TO BE USED IN CONNECTION WITH FIGURE 21 FOR DETERMINING SUBMERGED DISCHARGES FOR PARSHALL MEASURING FLUMES LARGER THAN 1-FOOT THROAT WIDTH*

Throat width, *W*, in feet	Factor, *M*	Throat width, *W*, in feet	Factor, *M*
1	1.0	5	3.7
2	1.8	6	4.3
3	2.4	7	4.9
4	3.1	8	5.4

* These factors are to be multiplied by the correction obtained from gure 21 and subtracted from the free-flow for the same upper head, H_a. table 10, to determine flow for submerged conditions. Computed from the expression $M = W^{0.815}$.

second. This amount is now multiplied by the factor 1.8 for a 2-foot flume, obtained from table 11; and the product, 0.9, is subtracted from the free-flow, 16.6 cubic feet per second, given in table 10, to obtain 15.7 cubic feet per second—the correct flow under these conditions.

Selection of Size and Proper Setting of the Parshall Measuring Flume.—The successful operation of the Parshall measuring flume depends largely upon the correct selection of size and the proper setting of the flume.[14] The probable maximum and minimum flow to be measured is estimated, and the maximum allowable loss of head is determined. The latter will depend upon the grade of the ditch and upon the freeboard (distance from normal water surface to top of banks) available at the place where the flume is to be installed.

The proper selection of size and crest elevation is important. When possible the selection should be such that free-flow will always result. For a given condition, it is desirable to assume different sizes and crest elevations and to determine corresponding submergences and maximum upstream water levels. For economy, the smallest flume that will satisfy the conditions may be selected.

[14] A more complete discussion on this subject is given in: Parshall, Ralph L. The improved Venturi flume. Colorado Agr. Exp. Sta. Bul. 336:1–84. 1928.

For example, suppose that a flume is to be installed in a ditch on a moderate grade and that the stream flow to be measured varies from 1 to 15 cubic feet per second. Assume that for the maximum flow the depth of water in the ditch is 2.5 feet and the freeboard is 6 inches, but that the banks could be raised slightly for a sufficient distance upstream from the flume and that the water level could be raised 6 inches with safety. The maximum allowable loss of head is therefore 6 inches. Table 10 indicates that flumes with a throat width of 1, 2, or 3 feet could measure the entire range of flow. Note that for a flow of 15 cubic feet per second, the head, H_a, would be 2.38 feet for a 1-foot flume, 1.50 for a 2-foot flume, and 1.16 for a 3-foot flume.

For free-flow, submergence should not exceed 60 per cent, so that the loss of head should not be less than 40 per cent of the head, H_a. The required loss for the 1-foot flume would be $0.4 \times 2.38 = 0.95$ foot; for the 2-foot flume, $0.4 \times 1.50 = 0.60$ foot; and for the 3-foot flume, $0.4 \times 1.16 = 0.46$ foot. The 3-foot flume is therefore the smallest size for which the maximum loss of head will be less than 6 inches.

The elevation at which the crest must be set to insure free-flow is next determined. The required depth upstream from the flume is $2.50 + 0.46 = 2.96$ feet; and the head, H_a, for 15 cubic feet per second is 1.16 feet. The crest should be set $2.96 - 1.16 = 1.8$ feet above the bottom of the ditch. If the 2-foot flume is selected, the depth upstream from it will be $2.50 + 0.60 = 3.10$ feet; and since the head, H_a, in this case is 1.50, the elevation of the crest should be $3.10 - 1.50 = 1.60$ feet above the bottom of the ditch. In order to use this flume, one would have to raise the ditch banks higher than assumed or to permit a maximum submergence of about 67 per cent, in which case the crest could be set 1.5 feet above the bottom of the ditch. Had the available loss of head been sufficient to permit the use of a 1-foot flume, the upstream depth would be 3.45 feet. The crest would then be set $3.45 - 2.38 = 1.17$ feet, say 1.2 feet, above the bottom of the ditch. The greater the throat width, the higher the crest must be set to insure free-flow operation.

Flumes should always be installed in a straight section of ditch with their center line approximately on the center line of the channel. The flow is little affected by the velocity of approach. The possibility of erosion downstream from the structure should be considered; and if necessary, the proper protection should be given to the channel before erosion occurs.

Construction.—Parshall measuring flumes may be built of wood, of concrete, or, in the smaller sizes, of heavy sheet metal. The dimensions of flumes ranging from 3 inches to 10 feet in throat width, are given in tables 12 and 13. To secure accuracy in measurement, these flumes must

TABLE 12

STANDARD DIMENSIONS OF PARSHALL MEASURING FLUMES FROM 3 TO 9 INCHES THROAT WIDTH

Dimension letter*	Dimensions in feet and inches for throat widths (*W*) of		
	3 inches	6 inches	9 inches
A	1′ 6⅜″	2′ 7/16″	2′ 10⅝″
2/3 *A*	1′ ¼″	1′ 4⅝″	1′ 11⅛″
B	1′ 6″	2′ 0″	2′ 10″
2/3 *B*	1′ 0″	1′ 4″	1′ 10⅝″
C	0′ 7″	1′ 3½″	1′ 3″
D	0′ 10⅜″	1′ 3½″	1′ 10⅝″
E	1′ 3″	1′ 6″	2′ 0″
F	0′ 6″	1′ 0″	1′ 0″
G	1′ 0″	2′ 0″	1′ 6″
K	0′ 1″	0′ 3″	0′ 3″
N	0′ 2¼″	0′ 4½″	0′ 4½″
X	0′ 1″	0′ 2″	0′ 2″
Y	0′ 1½″	0′ 3″	0′ 3″

* Letters refer to figure 22.

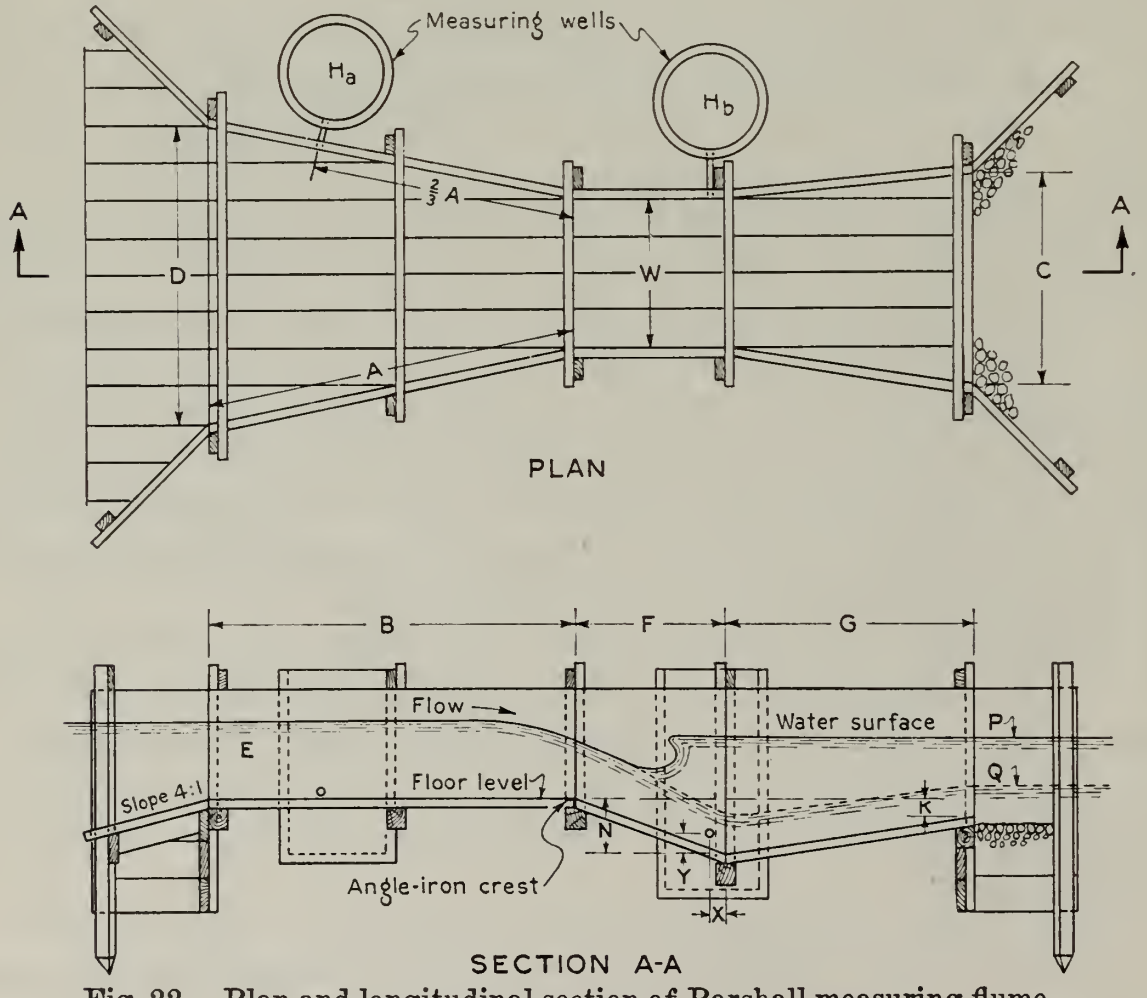


Fig. 22.—Plan and longitudinal section of Parshall measuring flume. Dimensions are given in table 12.

TABLE 13

STANDARD DIMENSIONS OF PARSHALL MEASURING FLUMES FROM 1 TO 10 FEET THROAT WIDTH

Throat width, *W*, in feet	Dimensions in feet and inches*					
	A	2/3 *A*	*B*	2/3 *B*	*C*	*D*
1.0	4′ 6″	3′ 0″	4′ 4⅞″	2′ 11¼″	2′ 0″	2′ 9¼″
2.0	5′ 0″	3′ 4″	4′ 10⅞″	3′ 3¼″	3′ 0″	3′ 11½″
3.0	5′ 6″	3′ 8″	5′ 4¾″	3′ 7⅛″	4′ 0″	5′ 1⅞″
4.0	6′ 0″	4′ 0″	5′ 10⅝″	3′ 11⅛″	5′ 0″	6′ 4¼″
5.0	6′ 6″	4′ 4″	6′ 4½″	4′ 3″	6′ 0″	7′ 6⅝″
6.0	7′ 0″	4′ 8″	6′ 10⅜″	4′ 6⅞″	7′ 0″	8′ 9″
7.0	7′ 6″	5′ 0″	7′ 4¼″	4′ 10⅞″	8′ 0″	9′ 11⅜″
8.0	8′ 0″	5′ 4″	7′ 10⅛″	5′ 2¾″	9′ 0″	11′ 1¾″
10.0	9′ 0″	6′ 0″	8′ 9⅞″	5′ 10⅝″	11′ 0″	13′ 6⅜″

* Letters refer to figure 23, in which other dimensions for these flumes are shown.

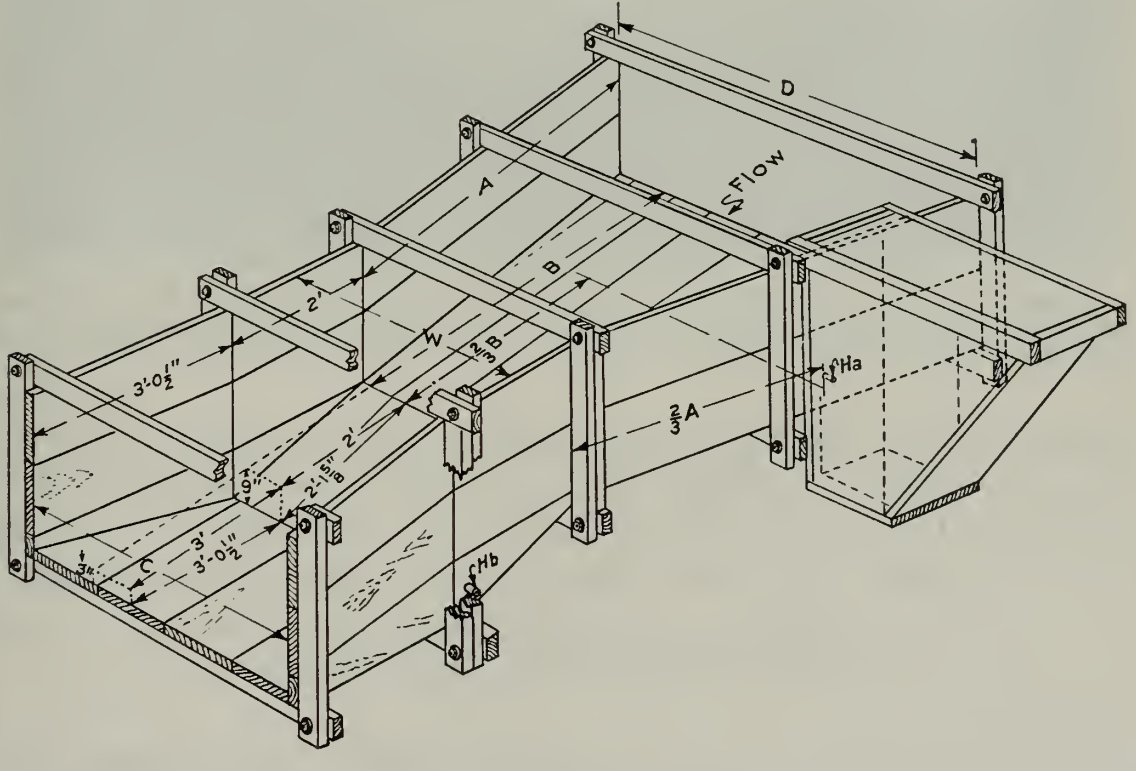


Fig. 23.—Perspective of Parshall measuring flume. Dimensions given are for flumes 1 foot and over, throat width. Lettered dimensions are given in table 13.

be built to exact dimensions, especially the converging and throat sections.

Small wooden flumes may be built as suggested by figures 22 and 23, with 4 × 4-inch sills, 2 × 4-inch posts and ties, and 1 or 2-inch lumber for the floor and sides. Two-inch lumber is recommended. Large structures will require larger sills and posts. For wooden structures in contact with the ground, all-heart redwood or treated lumber is recom-

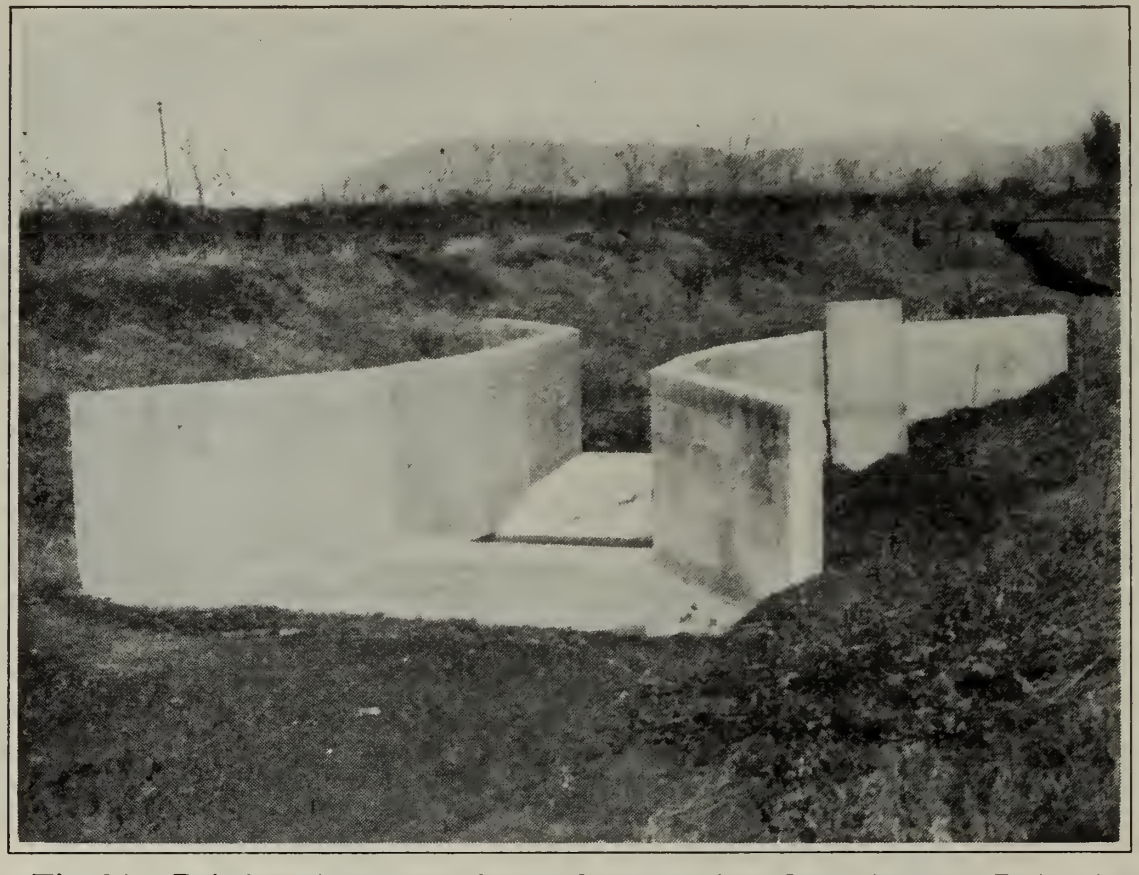


Fig. 24.—Reinforced concrete Parshall measuring flume in Alta Irrigation District, California. Throat width 4 feet. Photograph taken before earth was backfilled around side walls.

mended. The floor should be placed after the walls have been constructed and earth has been backfilled around the sills. Small cracks should be left between the boards in the walls and floor to allow for swelling of the lumber. With larger structures, special attention should be paid to the foundation to prevent uneven settling. Since large wooden structures tend to float, they should be securely anchored or bolted to concrete foundations.

The floor of the upstream converging section, especially the crest, must be level. An angle-iron crest, as indicated in figure 22, is recommended because it insures a true and definite edge. It should be set flush with the floor line and firmly held in place by screws with countersunk heads.

At both ends of the flume, wing walls should be provided. Those at

the upstream end should be placed at an angle of about 45 degrees with the center line of the flume. On the smaller flumes the lower wing walls may be placed at right angles to the flumes. All wing walls should extend into the natural banks of the channel. When the floor of the flume is more than 6 inches above the bottom of the channel, a short inclined floor should be provided at the entrance to the flume. This may be made of wood, as shown in figure 22, or it may be formed by filling in the channel with cobblestones or gravel.

If built of concrete (fig. 24), Parshall measuring flumes should be reinforced with steel, and the wing walls made a monolithic part of the structure (that is, cast as a single piece). Since the flumes are relatively short, no contraction joints need be provided. An angle iron embedded in the concrete to form the crest at the throat is recommended.

Small flumes of heavy galvanized sheet iron are rather easily constructed true to specified dimensions. Being semiportable, they may be moved and reinstalled without damage. They have a fairly long life and are not destroyed by burning grass and weeds during ditch-cleaning operations.

Stilling wells for measuring the head are essential if accuracy is desired. For flumes always operating under free-flow, only one such well is needed; but for submerged flow two are required. Stilling wells should be tight, as any material leakage may affect the accuracy of the measurement; and sufficiently large to permit cleaning the well and reading the gage. They may be made from wood, as shown in figure 23; or a length of concrete pipe 12 to 16 inches in diameter (fig. 22) makes a very suitable well. At the exact locations shown in figures 22 and 23, the wells should be connected to the flume with tightly fitting tubes about 1 inch in diameter, carefully placed so that the ends do not project inside of the flume.

Gages may be of any type similar to those described for use with weirs (page 21). Preferably, they should be graduated in feet, tenths, and hundredths instead of in feet and inches. The zeros of both gages are set level with the floor of the upstream converging section.

COMMERCIAL IRRIGATION METERS

A number of commercial meters are available for measuring irrigation water. They are usually operated by the flow of the water and arranged to register the total quantity passed; but the flow can be determined by timing the indicator hand. Although desirable under certain conditions, they involve numerous practical difficulties. One should therefore understand the limitations of any meter before purchasing it for a particular purpose.

Classification of Types.—Commercial meters operated by the flow of the water may be classified as displacement, velocity, and by-pass types.

The displacement meter measures volumetrically. The water, passing through, displaces a vane or disk, which in turn operates the recording mechanism. The operation is positive, and the measurement is fairly accurate regardless of the flow. Such meters generally require a greater loss of head than velocity meters and are relatively more expensive. Their use for measuring irrigation water is generally limited to pressure pipe lines in localities where water is fairly expensive, and flows less than 100 gallons a minute. Small meters of this type are extensively used for measuring domestic water.

Velocity meters, unlike the displacement meters, are operated by the kinetic energy of the moving water. They usually contain an impeller vane, turned by the water; and their operation is similar to that of a current meter (page 9). For high velocities, the impeller vane rotates at a rate almost directly proportional to the velocity of the water; but for low velocities it may turn more slowly, and below certain velocities it may not move at all. The critical velocity below which such meters are not dependable is fairly low. Because velocity meters are less expensive and can accommodate larger flows than displacement meters, they are more commonly used for measuring water for irrigation.

The by-pass meter operates somewhat differently from either velocity or displacement meters. Only a small part of the flow passes through the registering element, but the meter is calibrated to register the total volume that passes. It is used with some other device, such as a weir or orifice, and has somewhat the same operating characteristics as the velocity meter, since the percentage of water passing through it is not exactly constant but usually varies slightly with the flow.

Other types of commercial meters, being seldom used in irrigation, are not discussed in this bulletin.

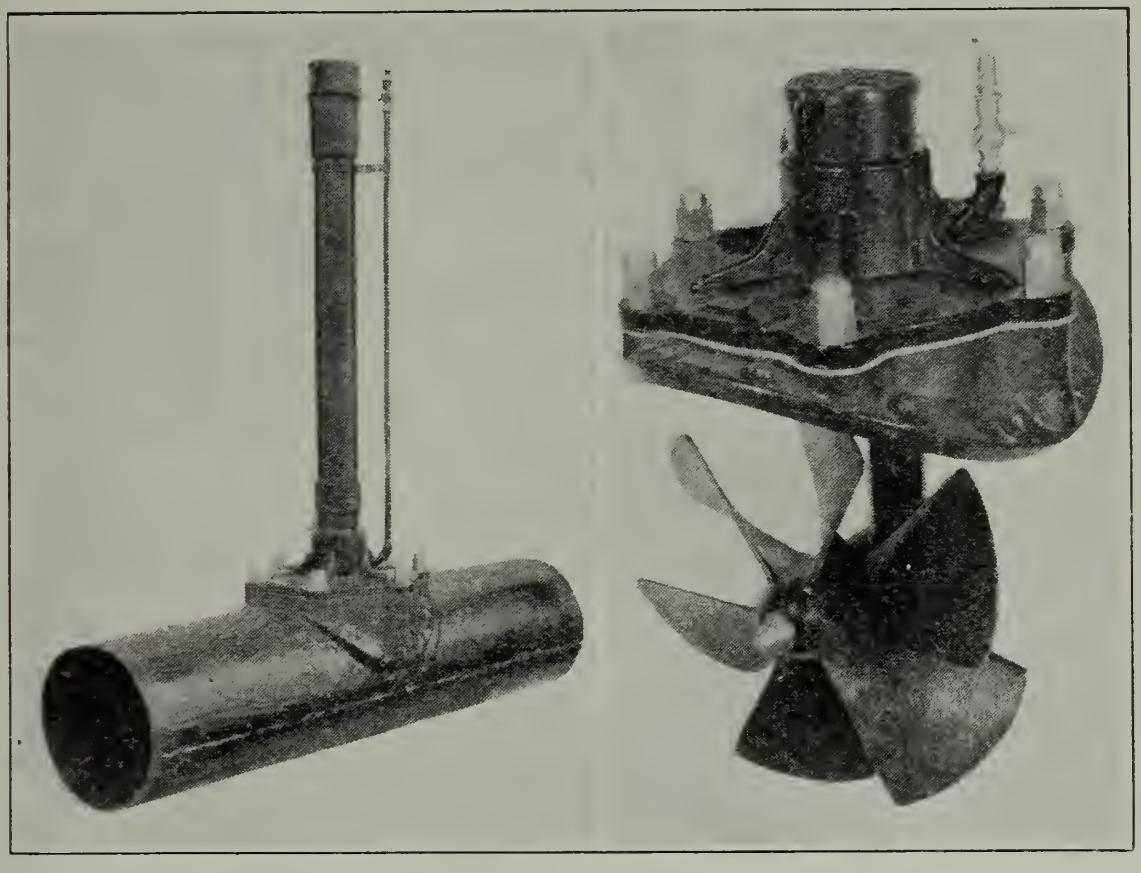
Advantages and Limitations.—Commercial meters have the advantage of eliminating computations in determining the total volume passed—an important feature when water is sold on a volume basis. Their convenience often justifies the expense involved.

Commercial meters, being subject to clogging, should never be used on pipe lines receiving water from open ditches unless the entrances are adequately screened to keep out débris. The by-pass type is less subject to trouble from this cause, but it should also be protected by screens.

Corrosion, sometimes accelerated by salts or alkalies in the water, may produce enough friction in certain moving parts of velocity meters to cause considerable error in the calibration. To overcome this difficulty, critical parts are sometimes made from noncorrosive metal.

Because velocity meters are limited to a definite range in flow, below which they will not register accurately, they are not satisfactory for measuring deliveries from pressure lines when the water is taken on demand and paid for on a quantity basis.

Probably the greatest limiting factor in all types of commercial



A *B*

Fig. 25.—Sparling meters. *A*, 8-inch meter mounted in a short section of welded pipe, with 2-foot register extension; *B*, 12-inch meter, showing construction of impeller wheel.

meters is their relatively high cost. To be satisfactory from an operating standpoint, they must be fairly rugged and durable. Cheap, delicately built meters have never proved satisfactory.

Sparling Meters.—Sparling main-line meters (fig. 25) are of the velocity type and are used on pipe lines ranging from 2 to 60 inches in diameter. The meter consists essentially of a six-blade impeller with a diameter about eight-tenths that of the pipe, mounted on a stainless-steel shaft which coincides with the axis of the pipe. By means of suitable extensions, the register, giving the volume passed in any desired unit, may be placed any distance above the pipe line or mounted on a wall. The flow can be determined by timing the indicator hand. Direct flow indicators and recorders are also available for use with these meters. By means of a special control, the register, indicator, or recorder, may be placed a remote distance from the meter.

For use in concrete pipe lines, meters, 6 inches or larger, are mounted in short sections of steel pipe, and installed in much the same manner as a length of concrete pipe. The 2 to 5-inch meters are mounted in a short brass tube tapped at each end for standard pipe.

Fig. 26.—Reliance irrigation meter installed on concrete pipe line. (From Cir. 250.)

The Sparling meter, though originally developed as an irrigation meter, proved well suited for waterworks and industrial uses and is now largely employed for these purposes.

Reliance Irrigation Meter.—This meter is of the velocity type. Figure 26 shows one installed on a concrete pipe line. It contains a brass screw-type impeller vane mounted on a vertical shaft and installed in a metal throat. The water flows vertically downward past the vane. This meter can be mounted in concrete or wooden structures and used with either open ditches or pipe lines. It is built in seven sizes ranging in capacity from ½ to 16 cubic feet per second.

Great Western Meter.—The Great Western meter (fig. 27) is of the by-pass type and is used with submerged orifices. Although this meter is no longer on the market, it is described because it represents the by-pass type. It is essentially a small displacement meter, through which a small

part of the water flows because of the differential head produced by the orifice. The flow through it passes a double set of screens. The impeller vane is mounted on a vertical shaft. A gear ratio can be selected so that the quantity of water passed will be registered in acre-feet or other units for any size of orifice. The meters can be used with circular orifices installed in concrete pipe lines or with rectangular orifices in open ditches.

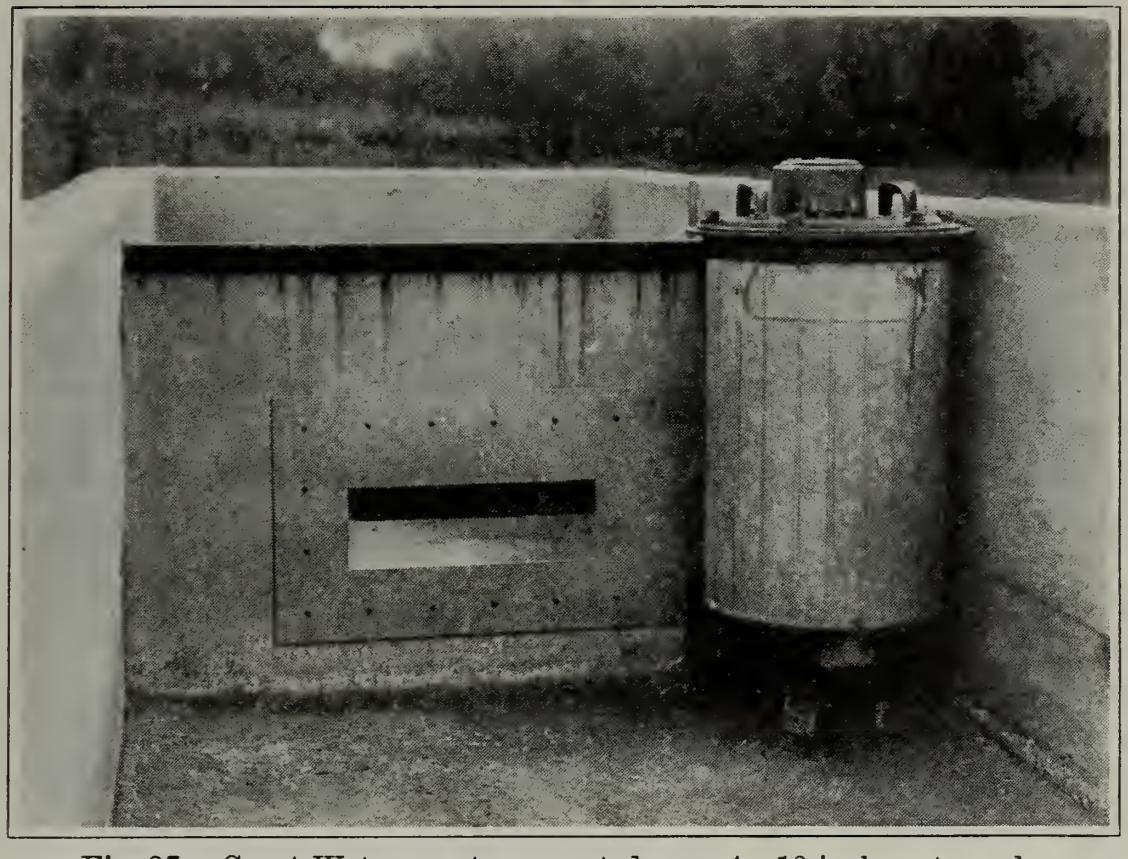


Fig. 27.—Great Wetern meter mounted on a 4 × 12-inch rectangular submerged orifice.

HYDRAULIC PRINCIPLES AND FORMULAS; METHODS OF WATER MEASUREMENT IN LIMITED USE

The purpose of this part of the bulletin is to assemble in a single publication concise statements of the hydraulic principles on which the methods and devices described in the first part are based and to discuss some methods of water measurement not ordinarily used in everyday irrigation practice. There has been no intention, however, of preparing a general treatise on hydraulics as applied to water measurement. It has seemed sufficient to state and explain the principles rather than to adopt the more technical procedure customary in texts and in classroom instruction. Mathematical symbols and formulas that would be out of place in the first part are, however, employed because they add to clearness and conciseness. The discussion of the less common methods may be of help to irrigation engineers, students in irrigation practice courses, and others who desire to extend their knowledge of water measurement.

SYMBOLS USED IN FORMULAS

The following symbols are used in the subsequent sections of this bulletin:

A, cross-sectional area as applied to orifices, pipes, Venturi tubes. Subscripts refer to areas at particular sections.

C, coefficient, in most instances the coefficient of discharge or the ratio of actual to theoretical flow.

D, diameter. Subscripts refer to diameters at different sections, as D_1 and D_2 in Venturi-tube formulas refer to pipe diameter at upstream pressure connection and throat diameter, respectively.

g, acceleration of gravity, approximately 32.2 feet per second per second.

h, head or elevation of water surface above a given reference plane. For weirs the head is measured from the crest; for free-flowing orifices, from the center of the orifice. For submerged orifices, Venturi tubes, etc., it is the difference in hydrostatic pressure at two sections expressed in height of water column.

h_v, velocity head $= \frac{V^2}{2g}$.

h_f, head lost through friction, etc.

H, total energy head, including velocity head.

K, constant, used in Francis' formula as an over-all constant including the coefficient.

L, length, length of weir crest, etc.

m, coefficient in weir formula.

M, a factor in Venturi-tube formulas, $= \frac{A_2\sqrt{2g}}{\sqrt{1 - r^4}} = \frac{A_1\sqrt{2g}}{\sqrt{R^4 - 1}}$

P, height of weir above bottom of approach channel.

Q, flow in cubic feet per second.

r, ratio of throat or orifice diameter to pipe diameter in Venturi-tube formula, $= \frac{1}{R}$.

R, ratio of pipe diameter to throat or orifice diameter in Venturi-tube formula, $= \frac{1}{r}$.

V, velocity. Subscript t indicates theoretical velocity.

y, vertical distance or ordinate.

Z, elevation above reference datum.

TORRICELLI'S THEOREM

In 1643, Torricelli, an Italian physicist, announced a principle now generally known as his theorem: *The velocity of a fluid passing through a small orifice in the side of a reservoir is the same as that which would be acquired by a body falling freely in a vacuum from a vertical height measured from the surface of the fluid in the reservoir to the center of the orifice.* This principle may be expressed by the equation

$$V_t = \sqrt{2\,g\,h} \qquad 1$$

BERNOULLI'S THEOREM

Bernoulli's theorem, announced in 1738, states: *At every section of a continuous and steady stream of frictionless fluid, the total energy head is constant; whatever energy is lost as pressure, is gained as velocity.* This theorem, modified to include the effect of friction, is often stated: *The energy head at any section of a flowing stream equals the sum of the energy head at any other downstream section and the intervening losses.* This may be expressed by the equation

$$h_1 + \frac{V_1^2}{2\,g} + Z_1 = h_2 + \frac{V_2^2}{2\,g} + Z_2 + h_f \qquad 2$$

where h_1 and h_2 are the pressure heads at the upstream and downstream sections, V_1 and V_2 are the corresponding velocities, Z_1 and Z_2 are the corresponding elevations with respect to a reference plane, and h_f is the head lost by friction between the two sections.

This theorem is the basis for nearly all formulas dealing with the flow of water. Torricelli's theorem is but a special case of Bernoulli's, and both express the law of conservation of energy.

ORIFICE MEASUREMENT

Orifice measurement is based essentially upon Torricelli's theorem. The theoretical flow through an orifice is given by the equation

$$Q_t = A\sqrt{2\,g\,h} \qquad 3$$

where A is the area of the orifice.

Because of the viscosity of the water and the contraction in the cross-sectional area of the jet a short distance from the orifice, the actual flow is somewhat less than this and is usually expressed by the equation

$$Q = C\,A\sqrt{2\,g\,h} \qquad 4$$

in which C is an experimentally determined coefficient, equal to the ratio of the actual flow to the theoretical flow.

A more precise expression for flow through a free-flowing orifice is

$$Q = C \int_{h_1}^{h_2} \sqrt{2\,g\,y}\; l\, dy, \qquad 5$$

where h_1 is the height of the water surface above the top of the orifice, h_2 is the height of the water surface above the bottom of the orifice, and y is the distance from the water surface to the center of gravity of an elementary horizontal strip across the orifice, having a length l and a height, dy. For rectangular orifices this expression when integrated becomes

$$Q = 2/3\; C\; L\; \sqrt{2\,g}\; (h_2^{3/2} - h_1^{3/2}). \qquad 6$$

Assuming a constant mean value for the coefficient C, the difference between equations 4 and 6 is less than 1 per cent when the head is greater than the height of the orifice.

Submerged orifices function in the same manner as free-flowing orifices. Since the jet is submerged and is subject to the hydrostatic pressure of the water below the orifice in addition to the atmospheric pressure, equation 4 correctly expresses the flow through such an orifice, even with very low heads. Under certain conditions, however, pressure head is partially recovered below a submerged orifice, and the coefficient will depend somewhat on the position at which the downstream head is measured.

The coefficient generally corrects for the contraction of the jet below an orifice, as previously mentioned. For accurate measurement, the contraction must be complete, since it is difficult to select the proper coefficient for partially suppressed contractions. Partial suppression of the contraction occurs (1) when the distance from the edges of the orifice to the sides or bottom of the channel of approach is less than about twice the least dimension of the orifice, (2) when two or more orifices are near each other in the same wall, or (3) when the edges of the orifice are rounded or the face of the wall is roughened near the orifice.

The coefficient for orifices varies slightly with their size and shape and with the head. Assuming complete contraction and the same head, H, it is a minimum for circular, slightly higher for square, and still higher for rectangular orifices, increasing slightly as the ratio of one dimension to another increases. It also decreases slightly as the head increases or as the dimensions of the orifice increase, being a maximum for very small orifices under low heads. The coefficients for submerged orifices are about the same as for orifices discharging into air, but are more constant for varying heads.

For complete contraction and varying sizes, shapes, and heads, the coefficient, C, ranges from about 0.59 to 0.66. A value of 0.61 is generally assumed for rectangular orifices with complete contraction. For partially suppressed contractions it may be anything from about 0.60 to almost 1.0, according to the conditions.

Correction for velocity of approach is usually made by adding the velocity head, h_v, to the measured head, h, to obtain the total energy head, H; that is, $h + h_v = H$. Because of the variation in velocity in the channel of approach, the velocity head calculated from the mean velocity will be somewhat less than that which actually produces the increased flow. The effect of the velocity of approach depends chiefly upon the ratio of the area of the orifice to the cross-sectional area of the water prism in the channel. When the conditions for complete contraction are satisfied, the error in flow caused by neglecting the velocity of approach will be less than 1 per cent.

WEIR MEASUREMENT

A weir is in theory only a special form of orifice lacking the upper edge, and the equations for flow over it are derived from Torricelli's theorem. Equation 5 is the basic weir formula when $h_1 = 0$—that is, when the upper edge of the orifice is at or above the water surface. Writing $h_2 = h$, and replacing C with m to avoid confusion (since the value of the coefficient will be different), equation 5 when integrated for rectangular weirs becomes

$$Q = 2/3\ m\ L\ \sqrt{2\ g}\ h^{3/2} = K\ L\ h^{3/2} \qquad 7$$

The formula for weirs of other shapes may be similarly derived from equation 5.

The effect of the energy of the water due to its velocity of approach can be taken into account by integrating equation 5 between the limits of $(h_1 + h_v)$ and $(h_2 + h_v)$, letting $h_2 = h$ and $h_1 = 0$, in which case

$$H = \left[(h + h_v)^{3/2} - h_v^{3/2}\right]^{2/3} \qquad 8$$

where h_v is the velocity head corresponding to the mean velocity of approach. This is the correction used in all the Francis formulas.

Three other methods are employed to take care of the velocity of approach (1) by providing a channel of approach of sufficient size that the velocity will be so small as to have a negligible effect, (2) by adding to the term h in the formulas an amount equal to the velocity head or to some function thereof that may be determined experimentally, or (3) by including in the coefficient m a factor that corrects for the velocity of approach. For contracted weirs the first method is generally

used. For velocities of approach less than 0.5 foot per second the velocity head may be considered negligible. For suppressed weirs either Francis' correction (equation 8) or one of the two latter methods is used. The correction for velocity of approach in the formula for discharge over rectangular suppressed weirs, from which table 14 is computed, is made by the third method.

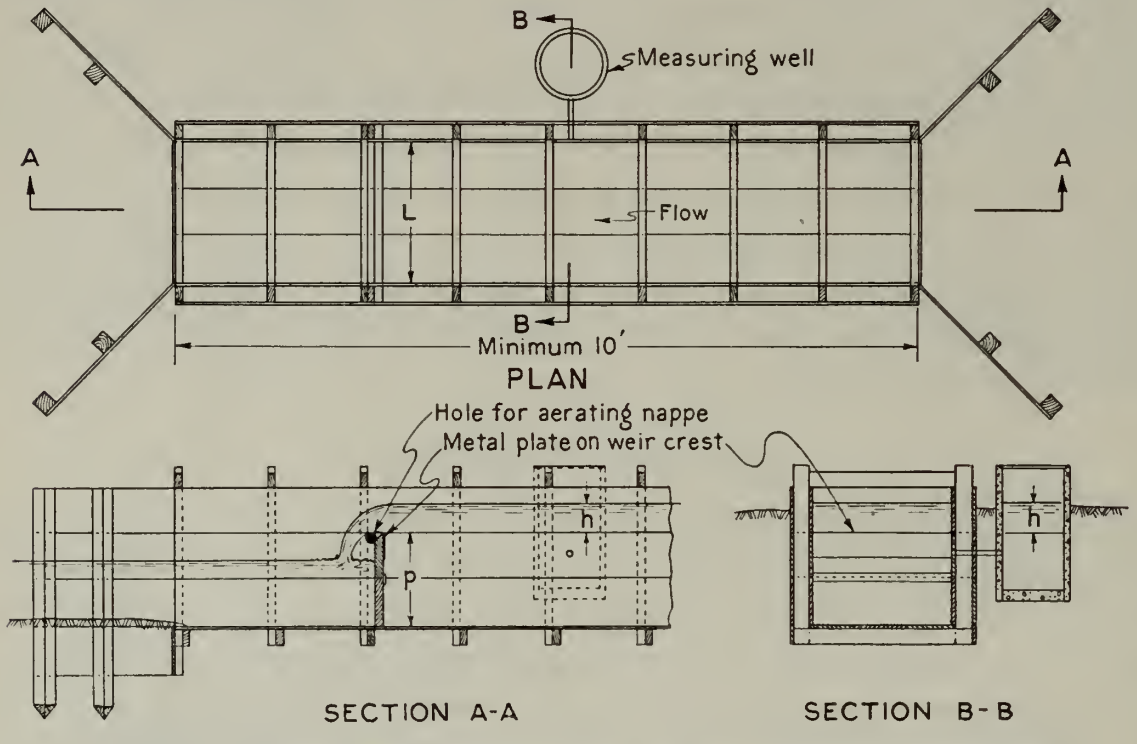


Fig. 28.—Plan, longitudinal section, and cross section of wooden suppressed weir structure.

Although the effect of contraction may be taken care of in the coefficient C for an orifice, the end contractions for a weir cannot be treated thus, because the coefficients m or K in this case would be variables dependent upon h. The correction for end contractions is generally made by subtracting from equation 7 an amount that is a function of the head. This correction has been determined experimentally, and many formulas have been suggested. Those upon which the tables in this bulletin are based are considered the most accurate available. Although empirical, they express very accurately the relation between discharge and head.

Rectangular Suppressed Weirs.—A rectangular suppressed weir structure consists essentially of a rectangular flume of uniform width and a vertical weir plate with horizontal crest. The length of the flume should be sufficient to obtain normally distributed velocities of approach, usually from 10 to 20 times the length of the weir crest. Artificial ventilation must be provided under the nappe below the weir crest to prevent the formation of a partial vacuum that decreases the head for a given flow. Openings with an area of ½ square inch per foot length of

weir crest will provide sufficient air for a maximum head of 1.5 feet. For greater heads, larger openings are required. Although not absolutely necessary, it is preferable that the height of the weir be greater than the maximum head to be measured. The crest should be sharp-edged and not more than about ¼ inch thick. The head should be measured a sufficient distance (usually 4 feet or more) upstream from the weir so that it is not affected by the downward curve of the water surface. It is desirable to provide a stilling well and to use a hook gage.

No particular type of suppressed weir structure is required to satisfy the conditions for accurate measurement. A suggested design for a wooden structure is shown in figure 28.

Formulas—Suppressed Weirs.—Of the many formulas proposed for determining the flow over weirs, only a few are well known or commonly used today. The most popular are the Francis formulas for flow over rectangular weirs, based on experiments conducted by J. B. Francis at Lowell, Massachusetts, between 1848 and 1852. Their continued popularity indicates their applicability to conditions under which water is measured.

The Francis formula for rectangular suppressed weirs is

$$Q = 3.33\ L\ H^{3/2} \qquad 9$$

in which $H^{3/2} = (h + h_v)^{3/2} - h_v^{3/2}$.

In general this formula gives low results except for high weirs and very low velocities of approach. It is approximately correct for weirs 1.5 feet or more in height and for heads greater than 0.2 feet but not more than one-third the height of the weir.

Several other formulas for suppressed weirs take the form

$$Q = 2/3\ m\ L\ \sqrt{2\ g}\ h^{3/2} \qquad 7$$

The best known of these are Bazin's formula in which

$$m = \left(0.607 + \frac{0.0148}{h}\right)\left[1 + 0.55\left(\frac{h}{h + P}\right)^2\right], \qquad 10$$

and Rehbock's formula in which

$$m = 0.605 + \frac{1}{320\ h - 3} + 0.08\ \frac{h}{P}, \qquad 11$$

where P is the height of the weir crest above the bottom of the approach channel.

Recent experiments by Schoder and Turner[15] at Cornell University indicate that the results of Bazin's formula are in general too high, and

[15] Schoder, E. W., and Kenneth B. Turner. Precise weir measurements. Amer. Soc. Civ. Engin. Trans. 93:999–1190. 1929.

that Rehbock's formula is approximately correct for weir heights up to 4 feet and for heads up to about 2 feet when the velocities are normally distributed in the approach channel. These experiments show, however, that the distribution of velocities in the channel of approach affects weir measurements, and that formulas of the usual type will not give accurate results unless these velocities are normally distributed. Baffles upstream from the weir are very helpful in securing the proper distribution of velocities. Table 14 is computed from a simplified form of Rehbock's formula in which

$$m = 0.605 + \frac{0.00328}{h} + 0.08\,\frac{h}{P} \qquad 12$$

This gives approximately the same results as formula 11 for values of h greater than 0.1 foot.

A new formula proposed by Cline[16] takes the form

$$Q = 3.276\,L\,(1.0195)^h\,h^f \cdot 10^{Kh} \qquad 13$$

in which

$$f = 1.5064\,h^{0.0081} \qquad 14$$

and

$$K = \frac{0.2713}{1 + 6.1452\,P^{3/2}} \qquad 15$$

Formula 13, also based upon the experiments of Schoder and Turner, fits the experimental data very closely. It is very difficult to use, however, and has little value except in the form of tables.[17]

Formulas—Contracted Weirs.—Formulas for contracted weirs are usually derived from suppressed weir formulas by correcting for the end contractions. The Francis formula is the most common and the easiest to use. The tables in the first part of the bulletin, however, were computed from Cone's formulas,[18] which are considered more accurate for small contracted weirs. They are not suitable for field computations because of the exponents involved.

The Francis formula for rectangular contracted weirs is

$$Q = 3.33\,(L - 0.2\,H)\,H^{3/2} \qquad 16$$

in which $H^{3/2} = (h + h_v)^{3/2} - h_v{}^{3/2}$. Usually it is sufficient to assume $H = h + h_v$. This formula gives results approximately correct for values

[16] Cline, C. G. Discharge formula and tables for sharp-crested suppressed weirs. Amer. Soc. Civ. Engin. Proc. 60(1):19. January, 1934.

[17] These tables may be secured from the Secretary of the American Society of Civil Engineers, 33 West 39th Street, New York City.

[18] Cone, V. M. Flow through weir notches with thin edges and full contractions. Jour. Agr. Research 5(23):1051–1113. March 6, 1916.

TABLE 14

Flow Over Rectangular Suppressed Weirs in Cubic Feet per Second*

Head, in feet	Head in inches, approx.	Weir height						
		0.5 foot	0.75 foot	1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet
		Flow in cubic feet per second per foot of weir crest						
0.10	1 3/16	0.111	0.110	0.109	0.109	0.108	0.108	0.108
0.11	1 5/16	0.127	0.126	0.126	0.125	0.125	0.125	0.124
0.12	1 7/16	0.145	0.144	0.143	0.142	0.142	0.141	0.141
0.13	1 9/16	0.163	0.162	0.161	0.160	0.159	0.159	0.159
0.14	1 11/16	0.182	0.180	0.179	0.178	0.178	0.177	0.177
0.15	1 13/16	0.202	0.200	0.199	0.197	0.197	0.196	0.196
0.16	1 15/16	0.223	0.220	0.219	0.217	0.216	0.216	0.215
0.17	2 1/16	0.244	0.241	0.239	0.238	0.237	0.236	0.235
0.18	2 3/16	0.266	0.263	0.261	0.259	0.257	0.257	0.256
0.19	2 1/4	0.289	0.285	0.283	0.280	0.279	0.277	0.277
0.20	2 3/8	0.312	0.307	0.305	0.302	0.300	0.299	0.299
0.21	2 1/2	0.336	0.331	0.328	0.325	0.324	0.322	0.322
0.22	2 5/8	0.361	0.355	0.352	0.349	0.347	0.345	0.344
0.23	2 3/4	0.387	0.386	0.376	0.372	0.370	0.369	0.368
0.24	2 7/8	0.413	0.406	0.401	0.397	0.395	0.393	0.392
0.25	3	0.440	0.431	0.427	0.422	0.420	0.418	0.416
0.26	3 1/8	0.467	0.458	0.452	0.447	0.445	0.442	0.442
0.27	3 1/4	0.495	0.485	0.479	0.473	0.471	0.468	0.467
0.28	3 3/8	0.524	0.513	0.506	0.500	0.498	0.495	0.493
0.29	3 1/2	0.554	0.541	0.535	0.527	0.524	0.521	0.520
0.30	3 5/8	0.583	0.569	0.562	0.555	0.552	0.548	0.545
0.31	3 11/16	0.614	0.599	0.591	0.583	0.580	0.576	0.574
0.32	3 13/16	0.645	0.629	0.620	0.612	0.608	0.604	0.602
0.33	3 15/16	0.677	0.659	0.650	0.641	0.637	0.633	0.631
0.34	4 1/16	0.709	0.690	0.681	0.670	0.666	0.662	0.660
0.35	4 3/16	0.742	0.722	0.711	0.701	0.696	0.691	0.688
0.36	4 5/16	0.775	0.754	0.743	0.731	0.725	0.721	0.717
0.37	4 7/16	0.810	0.787	0.774	0.762	0.757	0.751	0.748
0.38	4 9/16	0.844	0.819	0.807	0.793	0.788	0.782	0.778
0.39	4 11/16	0.881	0.853	0.840	0.826	0.819	0.813	0.809
0.40	4 13/16	0.916	0.888	0.873	0.858	0.851	0.844	0.840
0.41	4 15/16	0.952	0.922	0.907	0.890	0.883	0.876	0.872
0.42	5 1/16	0.990	0.958	0.942	0.924	0.917	0.908	0.904
0.43	5 1/8	1.03	0.994	0.976	0.958	0.950	0.941	0.937
0.44	5 1/4	1.07	1.03	1.01	0.993	0.983	0.974	0.969
0.45	5 3/8	1.10	1.07	1.05	1.03	1.02	1.01	1.00
0.46	5 1/2	1.14	1.10	1.08	1.06	1.05	1.04	1.04
0.47	5 5/8	1.18	1.14	1.12	1.10	1.09	1.08	1.07
0.48	5 3/4	1.22	1.18	1.16	1.13	1.12	1.11	1.10
0.49	5 7/8	1.27	1.22	1.19	1.17	1.16	1.15	1.14

* Computed from the simplified form of Rehbock's formula $Q = 2/3\ m\ L\ \sqrt{2\ g}\ h^{3/2}$, where $m = 0.605 + \frac{0.00328}{h} + 0.08\frac{h}{P}$ and P = height of weir crest above bottom of channel of approach.

TABLE 14—FLOW OVER RECTANGULAR SUPPRESSED WEIRS—(*Continued*)

Head, in feet	Head in inches, approx.	Weir height						
		0.5 foot	0.75 foot	1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet
		Flow in cubic feet per second per foot of weir crest						
0.50	6	1.31	1.26	1.23	1.21	1.20	1.18	1.18
0.51	6 1/8	1.35	1.30	1.27	1.24	1.23	1.22	1.21
0.52	6 1/4	1.39	1.34	1.31	1.28	1.27	1.25	1.25
0.53	6 3/8	1.44	1.38	1.35	1.32	1.30	1.29	1.28
0.54	6 1/2	1.48	1.42	1.39	1.36	1.34	1.33	1.32
0.55	6 5/8	1.52	1.46	1.43	1.40	1.38	1.36	1.36
0.56	6 11/16	1.57	1.50	1.47	1.44	1.42	1.40	1.39
0.57	6 13/16	1.61	1.54	1.51	1.48	1.46	1.44	1.43
0.58	6 15/16	1.66	1.59	1.55	1.52	1.50	1.48	1.47
0.59	7 1/16	1.71	1.63	1.60	1.56	1.54	1.52	1.51
0.60	7 3/16	1.76	1.68	1.64	1.60	1.58	1.56	1 55
0.61	7 5/16	1.80	1.72	1.68	1.64	1.62	1.59	1.58
0.62	7 7/16	1.85	1.77	1.72	1 68	1.66	1 63	1.62
0.63	7 9/16	1.90	1 81	1.77	1.72	1.70	1.68	1.67
0.64	7 11/16	1.95	1.86	1.81	1.76	1.74	1.72	1.71
0.65	7 13/16	2.00	1.90	1.86	1.81	1.78	1 76	1.75
0.66	7 15/16	2.05	1.95	1.90	1.85	1.82	1.80	1.79
0.67	8 1/16	2.10	2.00	1.95	1.90	1.87	1.84	1.83
0.68	8 1/8	2.15	2.05	1.99	1.94	1.91	1.88	1.87
0.69	8 1/4	2.21	2.09	2.04	1.98	1.95	1.93	1.91
0.70	8 3/8	2.26	2.14	2.08	2.03	2.00	1.97	1.95
0.71	8 1/2	2.31	2.19	2.13	2.07	2.04	2.01	2.00
0.72	8 5/8	2.37	2.24	2.18	2.12	2.08	2.05	2.04
0.73	8 3/4	2.42	2.29	2.23	2.16	2.13	2.10	2.08
0.74	8 7/8	2.48	2.34	2.28	2.21	2.18	2.14	2.12
0.75	9	2.53	2.39	2.32	2.25	2.22	2.18	2.17
0.76	9 1/8	2.59	2.45	2.37	2.30	2.27	2.23	2 21
0.77	9 1/4	2.65	2.50	2.43	2.35	2.31	2.27	2.26
0.78	9 3/8	2.70	2.55	2.48	2.40	2.36	2.32	2.30
0.79	9 1/2	2.76	2.60	2.52	2.45	2.41	2.37	2.35
0.80	9 5/8	2.82	2.66	2.58	2.49	2.45	2.41	2.39
0.81	9 11/16	2.88	2.71	2.63	2.54	2.50	2.46	2.44
0.82	9 13/16	2.94	2.76	2.68	2.59	2.55	2.51	2.48
0.83	9 15/16	3.00	2.82	2.73	2.64	2.60	2.55	2.53
0.84	10 1/16	3.06	2.87	2 78	2.69	2.64	2.60	2.58
0.85	10 3/16	3.12	2.93	2.84	2.74	2.69	2.65	2.62
0.86	10 5/16	3.18	2.99	2.89	2.79	2.74	2.69	2.67
0.87	10 7/16	3.25	3.04	2.94	2.84	2.80	2.74	2.72
0.88	10 9/16	3.31	3.10	3.00	2.90	2.84	2.79	2.76
0.89	10 11/16	3.37	3.16	3.05	2.95	2.89	2.84	2.81

TABLE 14—FLOW OVER RECTANGULAR SUPPRESSED WEIRS—(*Continued*)

Head, in feet	Head in inches, approx.	Weir height						
		0.5 foot	0.75 foot	1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet
		Flow in cubic feet per second per foot of weir crest						
0.90	10 13/16	3.43	3.22	3 11	3.00	2.95	2.89	2.86
0.91	10 15/16	3.50	3.27	3.16	3.05	2.99	2.94	2.91
0.92	11 1/16	3.57	3.34	3.22	3.11	3.04	2.99	2.96
0.93	11 3/16	3.63	3.40	3.28	3.16	3.10	3.04	3.01
0.94	11 1/4	3 70	3 46	3.33	3.21	3.15	3.09	3.06
0.95	11 3/8	3.76	3.52	3.39	3.26	3.20	3.14	3.11
0.96	11 1/2	3.83	3.58	3.45	3.32	3.26	3.19	3.16
0.97	11 5/8	3.90	3.64	3 51	3.37	3.31	3.24	3.21
0 98	11 3/4	3.97	3.70	3.57	3.42	3.36	3.29	3.26
0.99	11 7/8	4.04	3.76	3.62	3.48	3.41	3.35	3.31
1 00	12	4.11	3.82	3.68	3.54	3.47	3.40	3.36
1.01	12 1/8	.....	3.89	3.74	3.59	3.52	3.45	3.41
1.02	12 1/4	.....	3.95	3.80	3.65	3.58	3.50	3.47
1.03	12 3/8	.....	4.01	3.86	3.71	3.63	3.56	3.52
1.04	12 1/2	.....	4.08	3.93	3.77	3.69	3.61	3.57
1.05	12 5/8	.....	4.14	3.98	3.82	3.74	3.66	3.62
1.06	12 3/4	.....	4 21	4.04	3.88	3.80	3.71	3.67
1.07	12 13/16	.....	4.27	4.11	3.94	3.85	3.77	3.73
1.08	12 15/16	.....	4.34	4.17	4.00	3.91	3.82	3 78
1.09	13 1/16	.....	4.41	4 24	4 05	3.97	3.88	3.83
1.10	13 3/16	.....	4.48	4.30	4 12	4.02	3.93	3.89
1.11	13 5/16	.....	4 54	4.36	4 17	4.09	3.99	3.94
1.12	13 7/16	.....	4.61	4 42	4.23	4.14	4.04	3.99
1.13	13 9/16	.....	4.68	4.49	4.29	4.19	4.10	4.05
1.14	13 11/16	.....	4 75	4.55	4.36	4.26	4.15	4 11
1.15	13 13/16	.....	4.82	4.62	4.41	4.31	4.21	4.16
1.16	13 15/16	.....	4.89	4.68	4.47	4.37	4.27	4.22
1.17	14 1/16	.....	4.96	4.75	4.54	4.44	4.33	4.27
1.18	14 3/16	.....	5 03	4.82	4.60	4.49	4.38	4.33
1.19	14 1/4	.....	5.10	4.88	4.67	4.55	4.44	4.39
1.20	14 3/8	.....	5 17	4.95	4.72	4.61	4.50	4.44
1 21	14 1/2	.....	5 25	5.02	4.79	4.67	4.56	4.50
1.22	14 5/8	.....	5 32	5.09	4.85	4.73	4.61	4 56
1.23	14 3/4	.....	5 39	5.16	4.92	4.79	4 68	4.61
1.24	14 7/8	.....	5 47	5.22	4.98	4.88	4.73	4.67
1.25	15	.....	5.54	5.29	5.05	4.92	4.79	4.73
1.26	15 1/8	.....	.....	5 36	5.10	4.98	4.85	4.79
1.27	15 1/4	.....	.....	5.43	5 17	5.04	4.91	4.84
1.28	15 3/8	.....	.....	5.51	5.24	5.10	4.97	4.90
1.29	15 1/2	.....	.....	5.57	5.30	5.16	5 03	4 96

TABLE 14—FLOW OVER RECTANGULAR SUPPRESSED WEIRS—(*Concluded*)

Head in feet	Head in inches, approx.	Weir height						
		0.5 foot	0.75 foot	1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet
		Flow in cubic feet per second per foot of weir crest						
1.30	15 5/8	.....	.....	5.64	5.36	5.23	5.09	5.02
1.31	15 3/4	.....	.....	5.72	5.44	5.29	5.16	5.08
1.32	15 13/16	.....	.....	5.79	5.50	5.36	5.22	5.14
1.33	15 15/16	.....	.....	5.86	5.57	5.42	5.28	5.20
1.34	16 1/16	.....	.....	5.93	5.63	5.48	5.33	5.26
1.35	16 3/16	.....	.....	6.01	5.71	5.56	5.40	5.32
1.36	16 5/16	.....	.....	6.08	5.77	5.62	5.46	5.38
1.37	16 7/16	.....	.....	6.15	5.84	5.68	5.52	6.45
1.38	16 9/16	.....	.....	6.22	5.90	5.75	5.58	5.51
1.39	16 11/16	.....	.....	6.30	5.98	5.81	5.65	5.57
1.40	16 13/16	.....	.....	6.38	6.04	5.87	5.71	5.62
1.41	16 15/16	.....	.....	6.46	6.12	5.95	5.78	5.69
1.42	17 1/16	.....	.....	6.52	6.18	6.01	5.84	5.75
1.43	17 3/16	.....	.....	6.60	6.26	6.08	5.91	5.82
1.44	17 1/4	.....	.....	6.68	6.32	6.15	5.97	5.88
1.45	17 3/8	.....	.....	6.76	6.40	6.21	6.03	5.94
1.46	17 1/2	.....	.....	6.84	6.46	6.28	6.09	6.00
1.47	17 5/8	.....	.....	6.91	6.53	6.35	6.17	6.06
1.48	17 3/4	.....	.....	6.99	6.60	6.41	6.23	6.12
1.49	17 7/8	.....	.....	7.07	6.68	6.49	6.29	6.20
1.50	18	.....	.....	7.15	6.75	6.56	6.36	6.26

of H less than one-third the length of the weir crest, but slightly lower than given by Cone's formula. When the velocity of approach can be neglected, this formula may be simplified to

$$Q = 3.33\ (L - 0.2\ h)\ h^{3/2}\ . \qquad 17$$

Cone's formula for rectangular contracted weirs is

$$Q = 3.247\ L\ H^{1.48} - \left(\frac{0.566\ L^{1.8}}{1 + 2\ L^{1.8}}\right) H^{1.9}, \qquad 18$$

which fits very closely the experimental data and may be considered very accurate for weirs with complete contractions, for very low velocities of approach, and for heads greater than 0.2 foot. Tables 3 and 4, pages 18 and 22, are computed from this formula for heads between 0.1 and 1.5 feet and must be considered only approximate for heads less than 0.2 foot. Since the formula applies particularly to fully contracted weirs for which the velocity of approach is negligible, H is usually considered equal to h. Correction for velocity of approach may be made by

letting $H = h + h_v$, although accurate results cannot be expected if the velocity is appreciable.

The Cipolletti formula for Cipolletti weirs

$$Q = 3.367\ L\ H^{3/2} \qquad 19$$

was derived by Cesare Cipolletti, an Italian engineer, from his own and Francis' experiments. It gives approximately the same results as Cone's formula (given below) for values of H less than one-third the length of the weir crest and for crest lengths not greater than 4 feet. It is very convenient for field computations. Correction for velocity of approach is made as for the Francis formula for rectangular weirs.

Cone's formula for Cipolletti weirs is

$$Q = 3.247\ L\ H^{1.48} - \left(\frac{0.566\ L^{1.8}}{1 + 2\ L^{1.8}}\right) H^{1.9} + 0.609\ H^{2.5} \qquad 20$$

The experiments upon which this formula is based indicate that the side slopes of the Cipolletti weir (1 horizontal to 4 vertical) are too flat, that they overcorrect for end contractions, and that the flow through this weir is not proportional to the length of the weir crest as indicated by the Cipolletti formula. Table 5, page 25, for Cipolletti weirs, is computed from Cone's formula.

For 90-degree triangular-notch weirs, the Thomson formula,

$$Q = 2.54\ H^{5/2}, \qquad 21$$

is convenient for field computations, whereas Cone's formula

$$Q = 2.49\ H^{2.48} \qquad 22$$

can be conveniently used only in the form of a table (table 6, page 29). Cone's formula gives slightly greater values for Q than the Thomson formula for values of H less than 0.355, and vice versa.

CANAL HYDROGRAPHY

Canal hydrography includes measuring and analyzing the flow of water in irrigation canals and laterals. Continuous records of flow at various points on the system are indispensable in securing the proper distribution of water and in determining water requirements and seepage losses. The extent of hydrographic work of this nature varies widely with different systems, and the problems encountered are numerous. In many cases methods have been developed to meet specific requirements.

The use of most of the measuring devices described in the first part of the bulletin is limited to flows of less than about 100 cubic feet per second—sometimes because of the expense of the structure involved, but more often because of lack of available head, especially in canals

and laterals. Current-meter measurements (briefly discussed in the first part) are commonly used to rate stations at which continuous records of water stages are secured.

Rating Stations and Rating Flumes.—A rating station is a place where a known relation exists between the gage height or stage and the flow. This relation is ordinarily determined by making a number of current-meter measurements at different gage heights. The flow is plotted against the corresponding stage; and a smooth curve, called a rating curve, is drawn through the points. From it the flow for any other gage height may be determined. A continuous record can be kept of the stage, and current-meter measurements need be made only as required to determine the changes in channel conditions. Whenever possible, a rating station or flume should be above a control so that the relation between stage and flow will be constant.

A control is a section of the channel where the flow is a function of the stage and is independent of conditions downstream. On natural streams the control may be natural, consisting of rocky or tight portions of the channel where the cross section does not change and where there is sufficient slope so that the stage is not affected by backwater conditions. On a canal a drop structure with a permanent crest makes a good control. Frequently controls are not available in locations where rating stations are needed. In such cases a rating flume is desirable because it provides a permanent cross section for the stream and greatly facilitates current-meter measurements. These rating flumes are seldom satisfactory control stations, for the relation between gage height and discharge is often affected by downstream conditions of the channel, such as silting, growth of moss and water plants, and checkgates or other structures. Rating flumes are generally from 10 to 30 feet in length and rectangular in cross section, with a floor raised slightly above the bottom of the channel to prevent the deposition of silt. They may be of wood or concrete, the latter being preferable because of its permanence.

When adequate control is impractical, corrections for changing channel conditions are usually necessary. One method is to use a normal rating curve and to plot a chronological graph showing the corrections to be applied, as determined from frequent gagings. It is more difficult, although possible, to correct for changing slopes caused by the regulation of structures in the canal.

Gages at Rating Stations.—A gage is a graduated scale or other device for determining the stage, or gage height, at the rating station. The several types used for this purpose may be classed in two groups: (1) nonrecording or indicating gages and (2) recording gages. Very often these are installed not in the open channel but in a stilling well.

Nonrecording Gages.—Nonrecording types include staff gages, hook gages, weight gages, float gages, and others.

A staff gage is a scale, usually graduated in feet and tenths and sometimes in hundredths, mounted in a fixed vertical position in the channel or in a stilling well. Many kinds of graduations are used, according to the distance from which the gage must be read; the kind best suited to the conditions should be selected. A simple gage may be made by painting graduations and figures on a board; or an enameled iron gage may be secured from a firm handling engineering or hydraulic equipment.

An inclined staff or slope gage is similar to a vertical staff gage except that it is graduated for mounting in an inclined position. Since the graduations are farther apart, the readings may be made more accurately, under favorable conditions, than with a vertical gage. Otherwise, because of the difficulty in properly mounting them and in checking them later, inclined gages are less desirable than vertical gages.

Hook gages are generally considered the most accurate for determining water stages. They have two essential parts: a movable scale on which is fastened a hook, and a fixed part containing an index mark and usually a vernier scale. The movable part is raised until the point of the hook produces a slight "pimple" on the water surface, and the gage height is read opposite the index. A blunt or rounded point is preferable to a sharp point. These instruments are usually graduated in feet, tenths, and hundredths. On some instruments the vernier scale gives the reading to 1/1,000 foot. Because they permit the water level to be determined very accurately, hook gages are used with a number of water-measuring devices such as weirs, orifices, and Parshall measuring flumes. A simple type of hook gage suitable for rating stations is shown in figure 29. Three very satisfactory types particularly adapted for use with weirs and similar devices are shown in figure 30.

A weight gage consists of a heavy object which is lowered until it comes in contact with the water. The weight may be suspended upon a tape graduated to indicate the stage opposite a fixed index mark, or upon a chain with a mark indicating the gage height on a scale mounted in a fixed position. Gages of this type are very satisfactory for use on large streams, especially when the rating station is located at a bridge from which the weight may be suspended; but they are seldom used in measuring water for irrigation.

A float gage consists of a float attached to a staff, or to a chain or tape passing over a pulley and attached to a counter weight. It can be constructed to indicate the stage to any degree of accuracy desired. The graduations may be on the staff or tape or on a stationary scale. The accuracy depends primarily upon the size of float, the friction in the

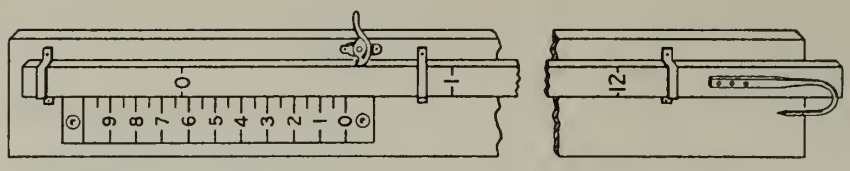


Fig. 29.—Simple type of hook gage commonly used at gaging stations.

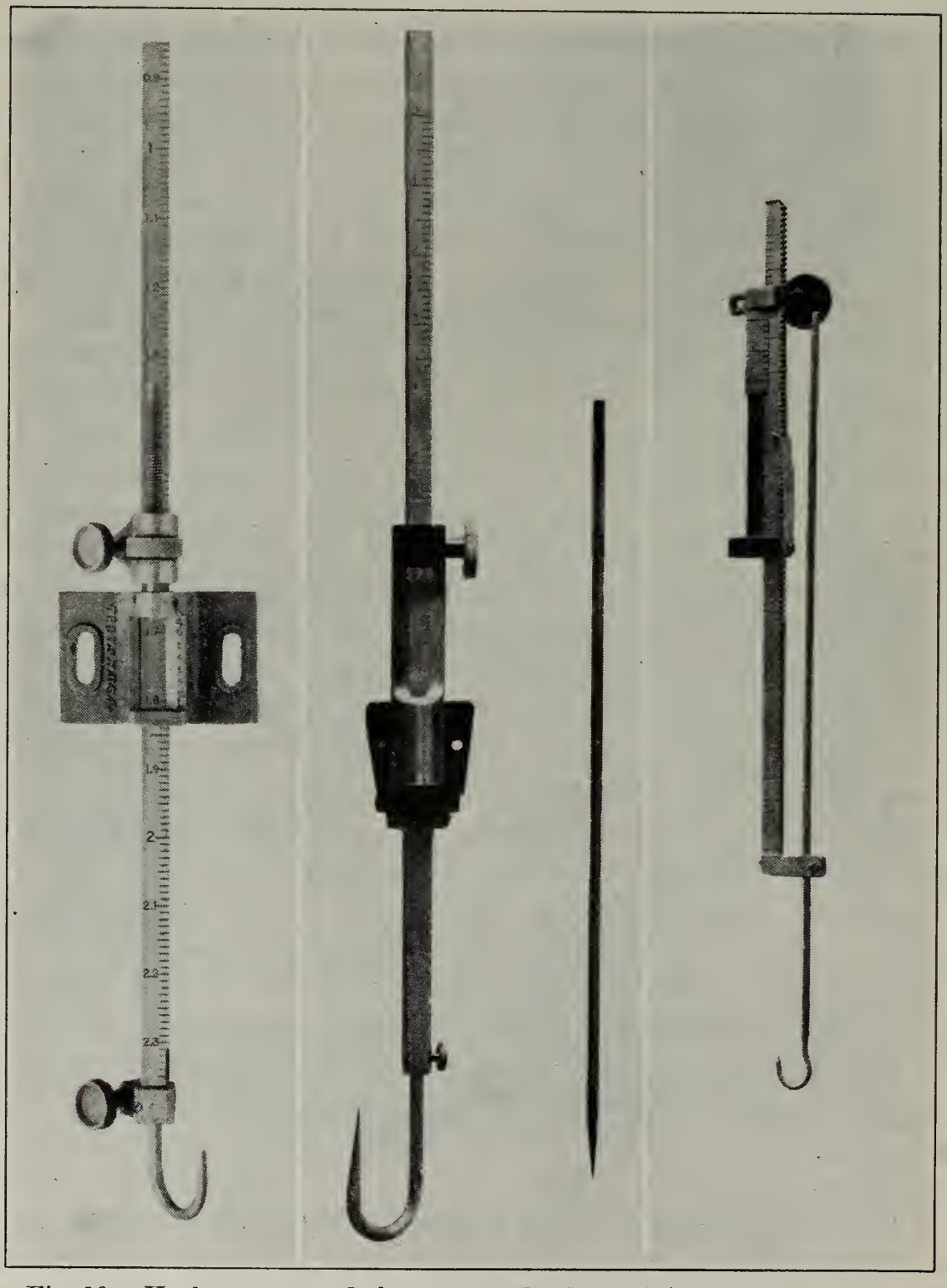


Fig. 30.—Hook gages used for accurately determining water levels: left, Gurley gage; center, combination point and hook gage designed and made by Department of Mechanical Engineering, University of California; right, gage designed and made by E. J. Hoff, Berkeley, California.

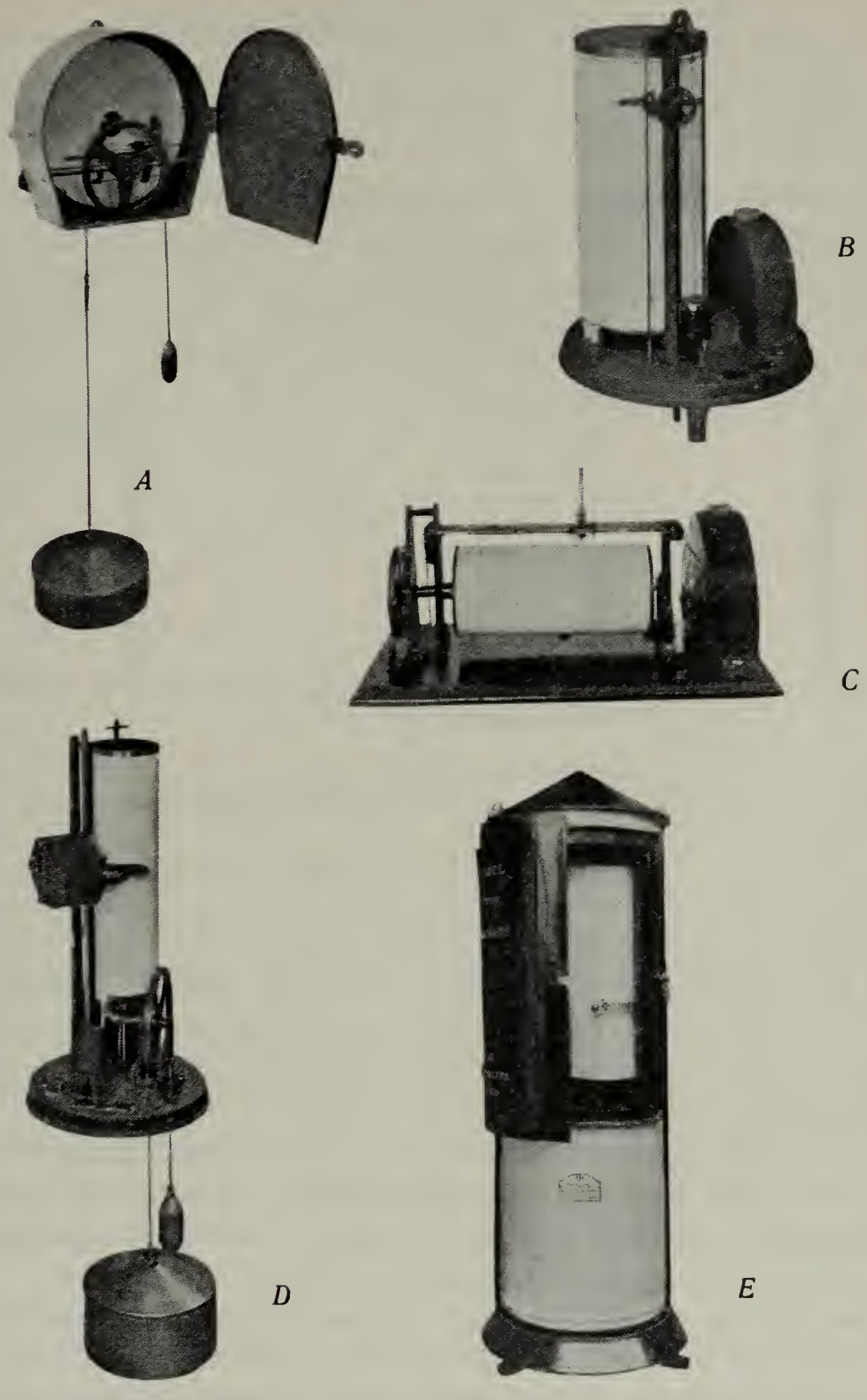


Fig. 31.—Water level recorders: *A*, Stevens type N; *B*, Stevens type L; *C*, Lietz; *D*, Stevens type E; *E*, Sparling.

pulley bearings or staff guides, and the change of length in the tape or chain due to wear or temperature variation. Such a gage is not subject to personal errors in setting as are hook and weight gages. Its chief disadvantage is that it must be adjusted and occasionally checked by a direct measurement to make sure that it reads correctly.

Recording Gages.—Recording gages (fig. 31), called water-level recorders or water-stage registers, are used to obtain a continuous graph of the gage height. The essential parts of a recording gage are (1) a float or pressure-indicating device, (2) a recording mechanism, and (3) a clock.

Several different kinds of recording gages are available. Generally a float revolves a drum containing a chart upon which a line is traced as the clock moves the pen or pencil. On some the clock revolves the drum, and the float moves the pen or pencil. The clock is operated by a spring

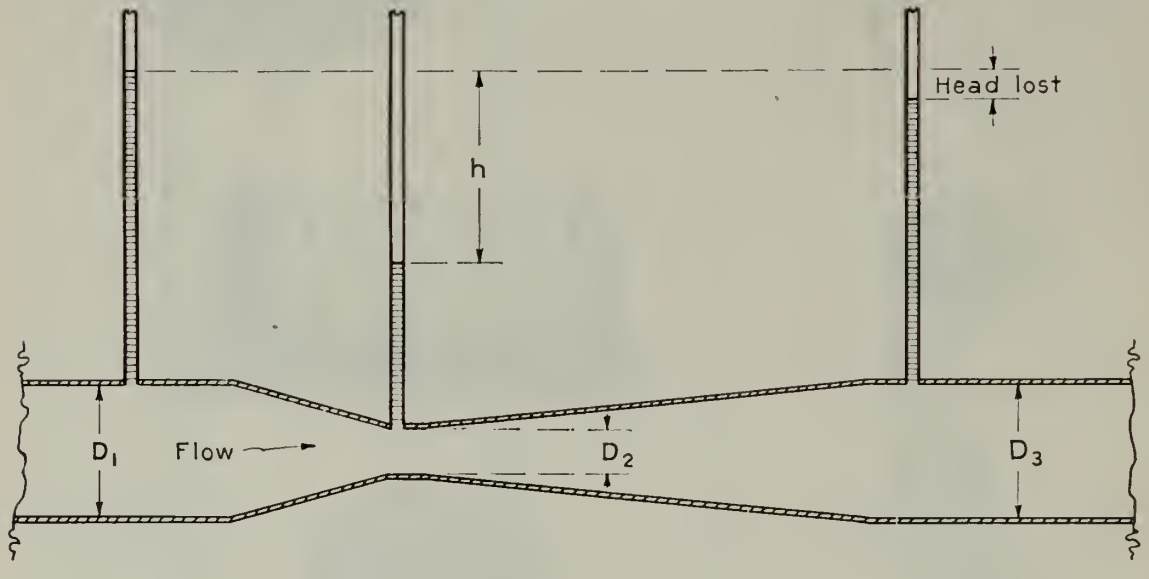


Fig. 32.—Diagram of Venturi tube.

mechanism, by weights, or electrically. Some recorders, with a clock operated by weights, will run from 30 to 90 days without attention, the chart being a long strip of paper that winds from one drum to another. On most recorders, however, the chart is graduated for either daily or weekly records.

Other recording gages, operating on a somewhat different principle, consist of a recording device mounted at any convenient place above the high-water level and attached by means of a tube to a submerged bulb which is sensitive to hydrostatic pressure.

Stilling Wells.—A stilling well, or measuring well, may be a box or piece of pipe set vertically at one side of the stream channel, with which it is connected by a small opening or pipe. It is used to eliminate wave action and provide a still water surface so that the stage may be measured accurately. Stilling wells, frequently used with other water-measuring devices, are necessary when precise measurements are desired. To function properly, the cross-sectional area of a stilling well should be about 100 times that of the inlet pipe or opening. Care must be taken to prevent the inlet pipe from clogging, and a convenient means of cleaning it should be provided.

VENTURI TUBES AND SIMILAR DEVICES

The Venturi Tube.—The term *Venturi meter* ordinarily refers to a complete water-measuring device, including an instrument for indicating, recording, or registering the flow. The essential part is the *Venturi tube* (fig. 32), consisting of a constricted portion of a cylindrical tube. As the water passes through the "throat," the velocity increases, and the pressure correspondingly decreases. By means of pressure connections upstream from the tapering section and at the throat, a differential head or pressure proportional to the velocity head, is obtained.

The equations for flow through a Venturi tube as derived from Bernoulli's theorem are

$$Q = \frac{C\,A_2\sqrt{2\,g\,h}}{\sqrt{1 - r^4}} \qquad 23$$

or

$$Q = \frac{C\,A_1\sqrt{2\,g\,h}}{\sqrt{R^4 - 1}} \qquad 24$$

or

$$Q = C\,M\sqrt{h} \qquad 25$$

in which A_1 and A_2 are the cross-sectional areas of the tube at the upstream and throat-pressure connections respectively. R is the ratio of pipe diameter to throat diameter $= \frac{D_1}{D_2}$ and r is the ratio of throat diameter to pipe diameter $= \frac{D_2}{D_1} = \frac{1}{R}$.

To avoid disturbances caused by valves or bends, a Venturi tube should be preceded by a length of straight pipe at least twenty times the pipe diameter. The gradually tapering exit cone recovers from 75 to 90 per cent of the velocity head by again converting it to pressure.

Although equations 23 and 24 are equally accurate, the one involving the throat area, A_2 (equation 23) is preferable because it emphasizes the most important cross-sectional area. An error of 1 per cent in measuring the throat diameter results in an error of 2 to 3½ per cent in the calculated flow, according to the ratio r; whereas the effect of a similar error in measuring the pipe diameter is usually negligible.

Tables 15 and 16 have been prepared to assist in solving equations 23 and 24. Table 15 gives values of the velocity head for heads up to 4.99 feet. For those not familiar with this kind of table, the following example may be helpful. To determine the theoretical velocity corresponding to a head of 2.87 feet find the line for a head of 2.8 feet in the

TABLE 15

THEORETICAL VELOCITIES IN FEET PER SECOND FOR HEADS FROM 0 TO 4.99 FEET*†

Head, in feet	Hundredth place									
	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	Velocity in feet per second									
0.0	0.00	0.80	1.13	1.39	1.60	1.79	1.96	2.12	2.27	2.41
0.1	2.54	2.66	2.78	2.89	3.00	3.11	3.21	3.31	3.40	3.50
0.2	3.59	3.68	3.76	3.85	3.93	4.01	4.09	4.17	4.24	4.32
0.3	4.39	4.47	4.54	4.61	4.68	4.74	4.81	4.88	4.94	5.01
0.4	5.07	5.14	5.20	5.26	5.32	5.38	5.44	5.50	5.56	5.61
0.5	5.67	5.73	5.78	5.84	5.89	5.95	6.00	6.06	6.11	6.16
0.6	6.21	6.26	6.31	6.37	6.42	6.47	6.52	6.56	6.61	6.66
0.7	6.71	6.76	6.80	6.85	6.90	6.95	6.99	7.04	7.08	7.13
0.8	7.17	7.22	7.26	7.31	7.35	7.39	7.44	7.48	7.52	7.57
0.9	7.61	7.65	7.69	7.73	7.78	7.82	7.86	7.90	7.94	7.98
1.0	8.02	8.06	8.10	8.14	8.18	8.22	8.26	8.30	8.33	8.37
1.1	8.41	8.45	8.49	8.53	8.56	8.60	8.64	8.68	8.71	8.75
1.2	8.79	8.82	8.86	8.89	8.93	8.97	9.00	9.04	9.07	9.11
1.3	9.14	9.18	9.21	9.25	9.28	9.32	9.35	9.39	9.42	9.45
1.4	9.49	9.52	9.56	9.59	9.62	9.66	9.69	9 72	9.76	9.79
1.5	9.82	9.86	9.89	9.92	9.95	9.99	10.02	10.05	10.08	10.11
1.6	10.14	10.18	10.21	10.24	10.27	10.30	10.33	10.37	10.40	10.43
1.7	10.46	10.49	10.52	10.55	10.58	10.61	10.64	10.67	10.70	10.73
1.8	10.76	10.79	10.82	10.85	10.88	10.91	10.94	10.97	11.00	11.03
1.9	11.05	11.08	11.11	11.14	11.17	11.20	11.23	11.26	11.28	11.31
2.0	11.34	11.37	11.40	11.43	11.45	11.48	11.51	11.54	11.57	11.59
2.1	11.62	11.65	11.68	11.70	11.73	11.76	11.79	11.81	11.84	11.87
2.2	11.90	11.92	11.95	11.98	12.00	12.03	12.06	12.08	12.11	12.14
2.3	12.16	12.19	12.22	12.24	12.27	12.29	12.32	12.35	12.37	12.40
2.4	12.43	12.45	12.48	12.50	12.53	12.55	12.58	12.61	12.63	12.65
2.5	12.68	12.71	12.73	12.76	12.78	12.81	12.83	12.85	12.88	12.91
2.6	12.93	12.96	12.98	13.01	13.03	13.06	13.08	13.10	13.13	13.15
2.7	13.18	13.20	13.23	13.25	13.28	13.30	13.32	13.35	13.37	13.40
2.8	13.42	13.45	13.47	13.49	13.52	13.54	13.56	13.59	13.61	13.63
2.9	13.66	13.68	13.70	13.73	13.75	13.77	13.80	13.82	13.84	13.87
3.0	13.89	13.91	13.94	13.96	13.98	14.01	14.03	14.05	14.07	14.10
3.1	14.12	14.14	14.17	14.19	14.21	14.23	14.26	14.28	14.30	14.32
3.2	14.35	14.37	14.39	14.41	14.44	14.46	14.48	14.50	14.53	14.55
3.3	14.57	14.59	14.61	14.63	14.66	14.68	14.70	14.72	14.74	14.77
3.4	14.79	14.81	14.83	14.85	14.88	14.90	14.92	14.94	14.96	14.98
3.5	15.00	15.02	15.05	15.07	15.09	15.11	15.13	15.15	15.17	15.20
3.6	15.22	15.24	15.26	15.28	15.30	15.32	15.34	15.36	15.39	15.41
3.7	15.43	15.45	15.47	15.49	15.51	15.53	15.55	15.57	15.59	15.61
3.8	15.63	15.65	15.68	15.70	15.72	15.74	15.76	15.78	15.80	15.82
3.9	15.84	15.86	15.88	15.90	15.92	15.94	15.96	15.98	16.00	16.02
4.0	16.04	16.06	16.08	16.10	16.12	16.14	16.16	16.18	16.20	16.22
4.1	16.24	16.26	16.28	16.30	16.32	16.34	16.36	16.38	16.40	16.42
4.2	16.44	16.46	16.48	16.50	16.51	16.53	16.55	16.57	16.59	16.61
4.3	16.63	16.65	16.67	16.69	16.71	16.73	16.75	16.77	16.79	16.80
4.4	16.82	16.84	16.86	16.88	16.90	16.92	16.94	16.96	16.98	16.99
4.5	17.01	17.03	17.05	17.07	17.09	17.11	17.13	17.14	17.16	17.18
4.6	17.20	17.22	17.24	17.26	17.28	17.29	17.31	17.33	17.35	17.37
4.7	17.39	17.41	17.42	17.44	17.46	17.48	17.50	17.52	17.53	17.55
4.8	17.57	17.59	17.61	17.63	17.64	17.66	17.68	17.70	17.72	17.73
4.9	17.75	17.77	17.79	17.81	17.83	17.84	17.86	17.88	17.90	17.92

* From: King, H. W. Handbook of hydraulics. p. 51. McGraw-Hill Book Company, New York. 1918. Computed from the formula $V_t = \sqrt{2\,g\,h}$

† To assist in solving formulas for flow through Venturi meters, orifices, etc.

left column and follow to the right to the column headed 0.07 and read the velocity 13.59 feet per second.

Interpolation may be used to determine velocities corresponding to heads measured to the nearest 1/1,000 of a foot. For example, to determine the velocity corresponding to a head of 0.453 feet, find the velocity

TABLE 16

VALUES OF r, R, $\sqrt{1-r^4}$, AND $\sqrt{R^4-1}$ FOR DIAMETER RATIOS COMMONLY USED FOR VENTURI TUBES, FLOW NOZZLES, AND ORIFICES*

r	R	$\sqrt{1-r^4}$	$\sqrt{R^4-1}$
0.300	3.333	0.996	11.064
.333	3.000	.994	8.944
.375	2.667	.990	7.042
.400	2.500	.987	6.169
.417	2.400	.985	5.673
.438	2.285	.981	5.123
.500	2.000	.968	3.873
.562	1.777	.949	2.995
.583	1.714	.940	2.763
.600	1.667	.933	2.591
.625	1.600	.921	2.356
.667	1.500	.896	2.015
700	1.428	.872	1.773
.750	1.333	.827	1.470
0.800	1.250	0.768	1.201

* For definitions of symbols see page 68.

for a head of 0.45 foot = 5.38 feet per second, and for a head of 0.46 feet = 5.44 feet per second. The difference is 0.06 feet. Multiply this by 0.3, corresponding to the last figure of the desired head, to get 0.018, or 0.02 to the nearest one hundredth, and add to 5.38 to get 5.40 which is the correct velocity for a head of 0.453 feet.

Table 16 gives values of the radicals $\sqrt{1-r^4}$ and $\sqrt{R^4-1}$ for diameter ratios commonly used for Venturi tubes, flow nozzles, and orifices. From these tables, the flow may be easily computed, or flow tables or diagrams may be readily constructed for Venturi tubes and similar devices.

Use of Venturi Meter for Measuring Irrigation Water.—Although the Venturi tube was invented by Clemens Herschel in 1889 and has been used extensively for measuring flow in pipe lines of diameters ranging from a few inches to several feet, it has been used to only a limited extent for irrigation water. The standard Venturi tubes have generally been considered too expensive for irrigation purposes. Their proportions are not entirely suited to conditions encountered in irrigation, the conical sections being too long to be constructed conveniently.

The ratios of pipe diameter to throat diameter generally are too high, causing too large a loss of head.

The first Venturi meter for irrigation service was developed by a manufacturer of standard Venturi tubes to meet the requirements of irrigation practice. It included an instrument to record the flow. Being expensive, it never became popular; nor was it used to any great extent in California.

TABLE 17

DIMENSIONS OF VENTURI TUBES USED BY CONSOLIDATED IRRIGATION DISTRICT, SELMA, CALIFORNIA

Dimensions* of tubes in inches						Ratios		Areas in square feet		M†
D_1	D_2	D_3	L_1	L_2	L_3	R†	r†	A_1†	A_2†	
16	9¼	16	18	9¼	31	1.730	0.578	1.40	0.467	3.97
20	12	20	19	12	29	1.667	0.600	2.18	0.785	6.75
24	14	24	24	14	36	1.714	0.584	3.14	1.070	9.13
30	21	30	24	21	56	1.428	0.700	4.91	2.405	22.13
42	28	42	40	28	60	1.500	0.667	9.62	4.277	38.27

* The letters refer to figure 33.

† For definition, see pages 68 and 85.

Consolidated Irrigation District Venturi Tube.—Recently, however, modified Venturi tubes for measuring irrigation water have been developed by the Consolidated Irrigation District, near Fresno, and are used principally for measuring deliveries from the larger canals to small laterals and private ditches. They have been in use for several years and have proved entirely satisfactory.

The standard installation of the Consolidated Irrigation District Venturi tube is shown in figure 33, the dimensions of which are given in table 17. The tube consists of three parts: (1) a short entrance section of uniform diameter containing the entrance piezometer ring and pressure connection, (2) the combined entrance cone and throat sections with the throat piezometer ring and pressure connection, and (3) the exit cone of gradual taper providing a return to the original diameter. Except in the 42-inch size, these sections are precast in heavy sheet-metal forms and are reinforced with ¼-inch steel bars. The tubes are installed in much the same manner as concrete pipe. The 42-inch size is built in place.

Piezometer rings, at both entrance and throat, consist of ½-inch or ¾-inch iron pipes embedded in the wall of the section with four or five equally spaced ⅜-inch holes drilled through from the inside of the tube. The entrance ring is located 12 inches upstream from the cone; the throat ring, midway along the throat section.

For smaller tubes, the measuring well consists of one or two joints of concrete pipe about 16 inches in diameter divided by a heavy galvanized sheet-metal partition. For larger tubes, especially with deep wells, two separate concrete pipes about 12 inches in diameter are used.

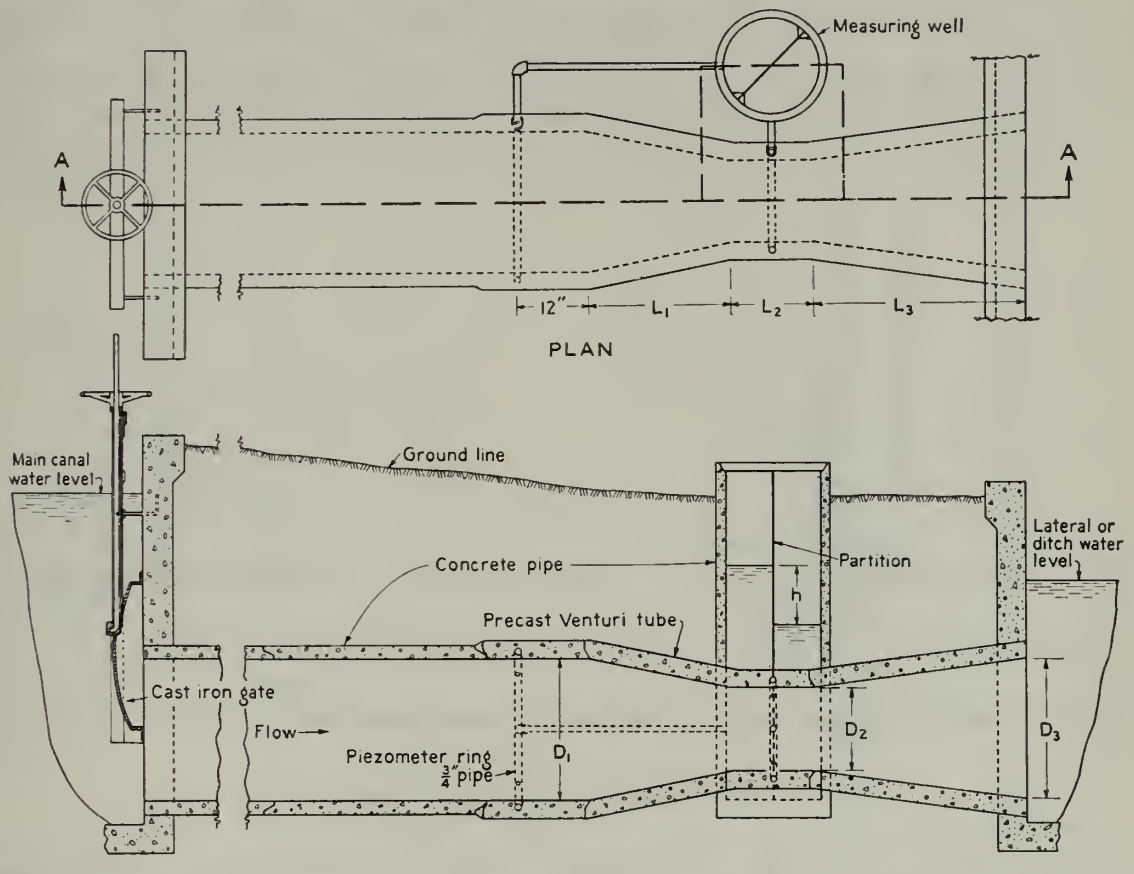


Fig. 33.—Plan and longitudinal section of Consolidated Irrigation District Venturi tube.

Experience has shown that these Venturi tubes can be made by the irrigation district for approximately the cost of the same length of concrete pipe. Since they are installed as part of standard headgate structures, their actual cost, represented by the difference in cost of installing similar structures with and without them, averages about $8 each.

Since these tubes are of somewhat different shape from standard Venturi tubes, the coefficient was determined from field tests, which showed the coefficient to be approximately 0.96 for the 16, 20, and 24-inch sizes, and 0.97 for the 30 and 42-inch sizes. Tests[19] on a 12-inch model at Davis gave a coefficient of about 0.95 for throat velocities greater than 3 feet per second. The coefficient was less for low throat velocities, increasing from about 0.8 for a throat velocity of 1 foot per second. When the formula was modified and written

$$Q = C\,M\sqrt{h - 0.006}\,, \qquad 26$$

the coefficient became a constant equal to 0.954.

[19] Christiansen, J. E., and I. H. Teilman. A practical Venturi meter for irrigation service. Engin. News-Rec. 106:187–188. January 29, 1931.

Advantages and Limitations.—The Venturi tubes just described are desirable as irrigation measuring devices for several reasons. With them, less head is lost than with any other practical device—usually less than 20 per cent of the head measured. They are more accurate than most other devices. They are well adapted for measuring flow up to 50 cubic feet per second, either in open channels or in pipe lines; and especially for measuring deliveries to small laterals and private ditches, since they can be combined with turnout structures at little additional cost. Being

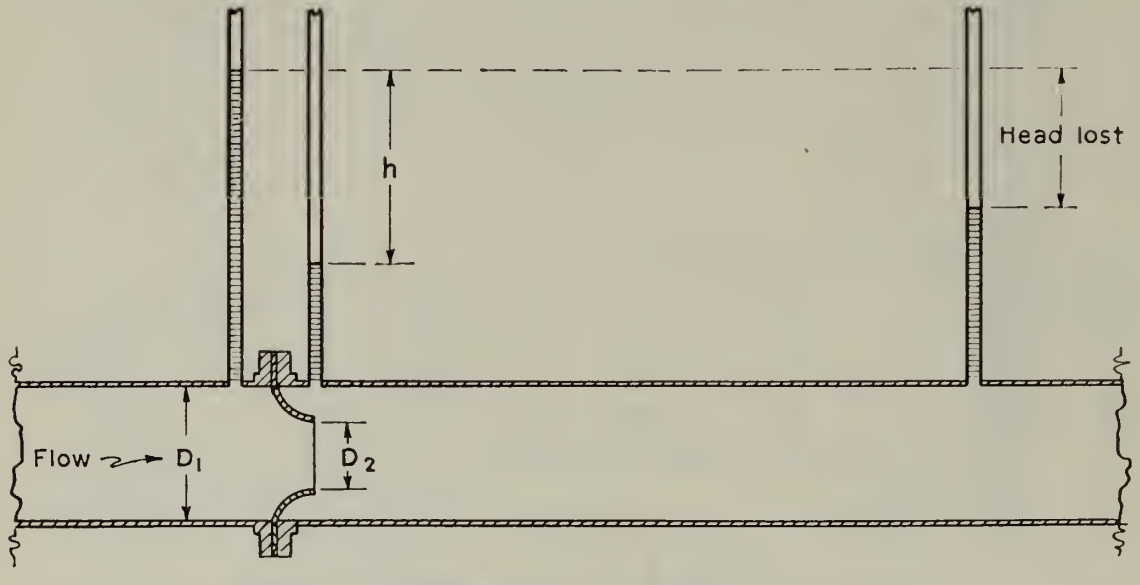


Fig. 34.—Diagram of flow nozzle in pipe line.

durable, with no moving parts, they require practically no attention. They are convenient, since tables or diagrams may be prepared giving the flow for different heads; and they are suitable for use with gages that indicate or record the flow, or with devices that register the total volume passed.

One limitation of Venturi tubes for irrigation service is the lack of standardized sizes and shapes and of information regarding the coefficients. They are rather difficult for individuals to construct and install and they are relatively expensive except when made in quantities. They may not be entirely suitable for water carrying large amounts of silt, because of possible clogging of the pressure connections, which are not easily cleaned. Furthermore, they are still in the stage of development.

Flow Nozzles.—Since the principles underlying the use of flow nozzles are the same as for Venturi tubes, identical formulas apply.[20] Flow nozzles have been little used for measuring irrigation water, but they have been utilized somewhat by pump manufacturers and laboratories for testing pumps. Recently a modification of the flow nozzle has been developed by Fresno Irrigation District for use in connection with turnout structures to farms.

[20] See formulas 23, 24, and 25, page 85.

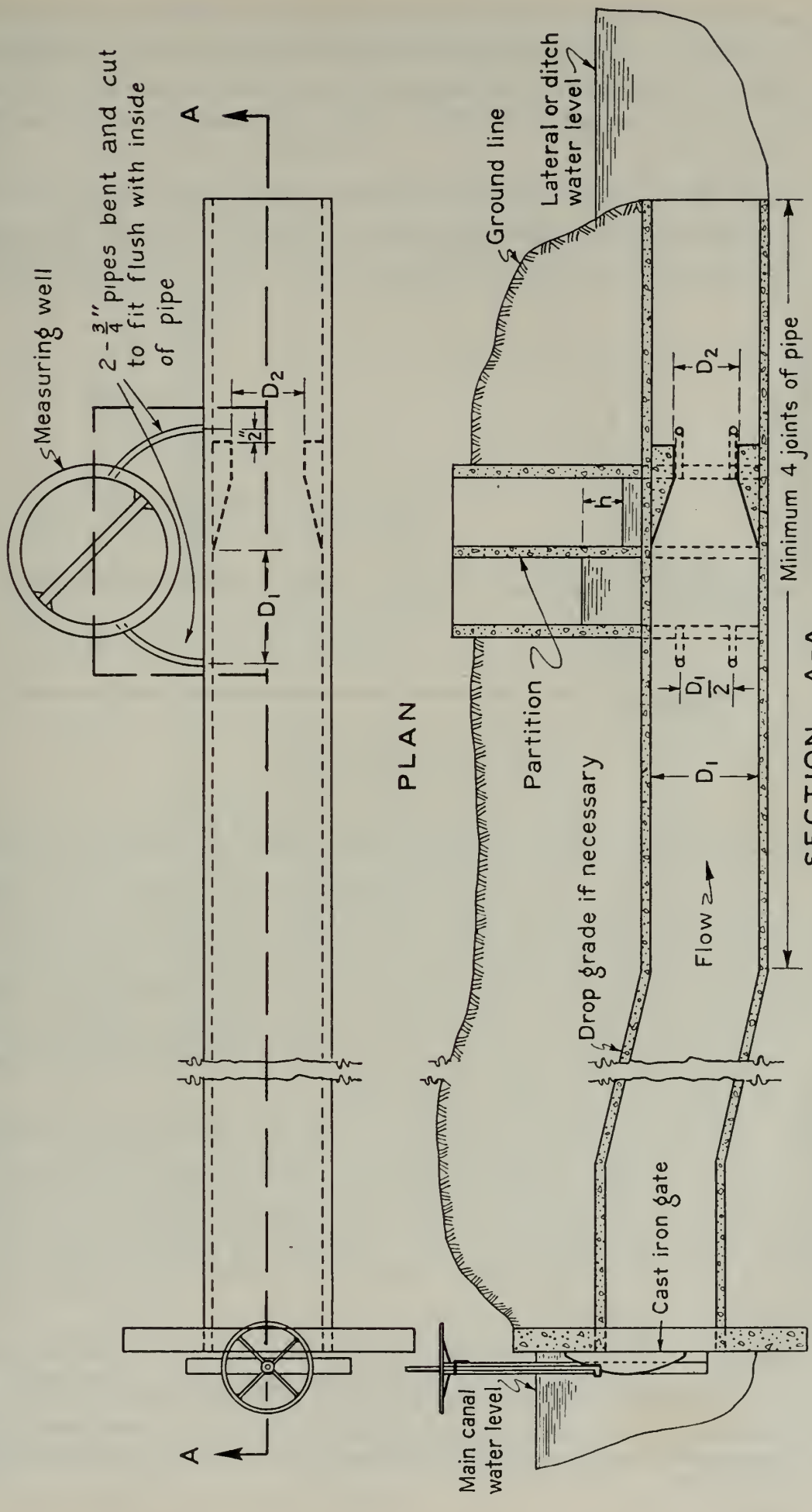


Fig. 35.—Plan and longitudinal section of Fresno Irrigation District flow meter.

The essential features of this device are shown in figure 34. Experiments reported by the American Society of Mechanical Engineers[21] indicate that by placing the downstream pressure connection as shown, the same result is obtained as if the connection were through to the inside of the throat.

The shape of the nozzle allows the water to issue from the throat section in a straight cylindrical jet without contraction, so that the coefficient is almost the same as for the Venturi tube. The principal difference

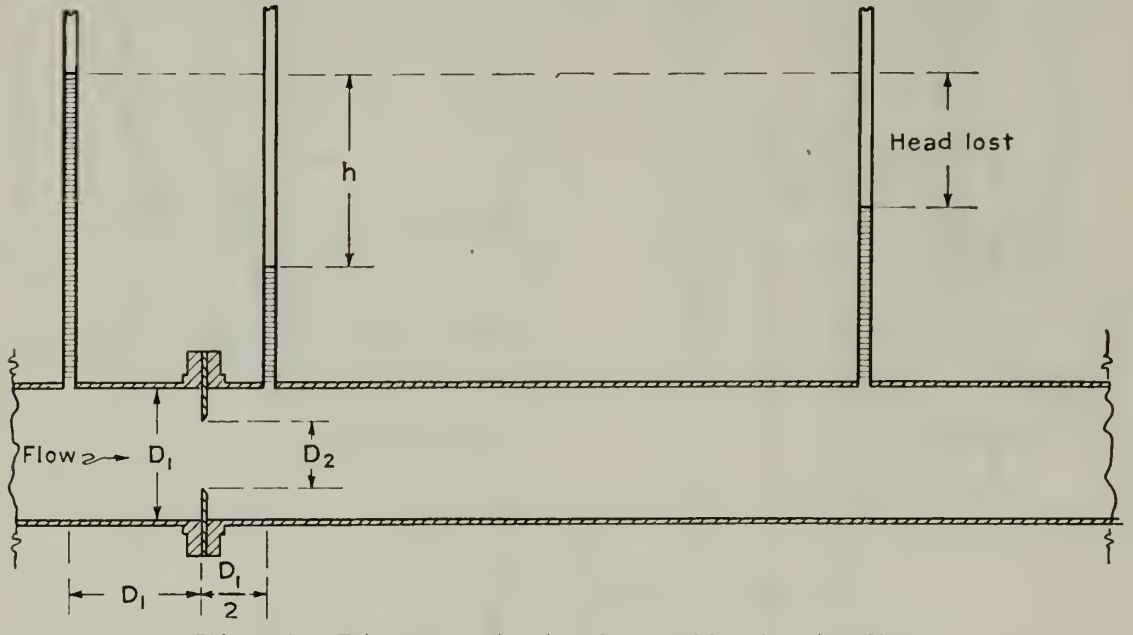


Fig. 36.—Diagram of thin-plate orifice in pipe line.

is in the recovery of head. In the flow nozzle, the jet is allowed to expand of its own accord, resulting in a considerably greater loss of head than for a Venturi tube. The experiments previously mentioned indicate that the loss of head depends upon the ratio of throat diameter to pipe diameter and varies from about 30 per cent of the differential head when that ratio is 1 : 1.25, to more than 90 per cent when the ratio is 1 : 5.0. The ratio most commonly used is about 1 : 2, for which the loss of head is about 60 per cent of the differential head.

Fresno Irrigation District Flow Meter.—The modification of the flow nozzle used by Fresno Irrigation District for measuring deliveries is shown in figure 35. It is called a "flow meter" by the district and is used principally where the calibrated gate[22] is not entirely satisfactory, especially when there is a considerable difference in water level between the supply ditch and the farmer's ditch.

The particular form of this flow meter was chosen to facilitate construction. The meter is cast into a length of concrete pipe by means of

[21] American Society of Mechanical Engineers Special Research Committee on Fluid Meters. Fluid meters, their theory and application. 3rd ed. Amer. Soc. Mech. Engin., New York City. 1931.

[22] See page 40.

an inside metal form. The diameters of both entrance and throat sections are measured for each individual flow meter, and the flow tables used are arranged to correct for minor variations in the ratios of these diameters. The head is measured in a well of the type used for the Venturi tubes and for calibrated gates.

Each size of meter has been calibrated by tests conducted by Fresno Irrigation District.[23] Coefficients calculated from these calibrations vary from about 0.86 to 0.96 and average about 0.92. No apparent relation

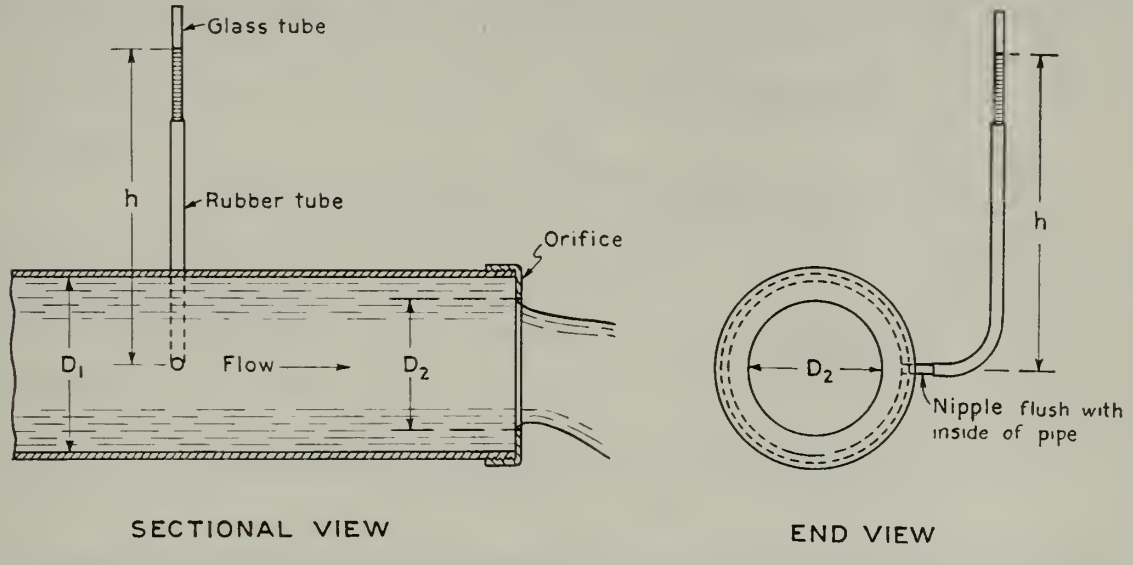


Fig. 37.—Thin-plate orifice screwed on end of pipe, used to measure flow from pumping plants.

exists between the diameter of the pipe and the coefficient, nor between the ratio R and the coefficient. Discharge tables for field use are based upon the calibration for each size of meter.

Thin-Plate Orifices in Pipe Lines.—For a number of years, thin-plate or sharp-edged orifices have been used to measure flow in open channels. Only recently, however, has the behavior of orifices in pipe lines been systematically studied. A thin-plate orifice in a pipe acts like a Venturi tube or flow nozzle, and the same formulas[24] are used, although the coefficient has a somewhat different physical significance and a smaller value. As shown in figure 36, the upstream pressure connection is usually located about one diameter of the pipe upstream from the orifice. Its exact position, however, is not important, since the pressure is practically uniform for a distance of one-half to two pipe diameters above the orifice.

The location of the downstream pressure connection is very important.

[23] The results of these tests, together with a more complete description of the flow meter and tables of discharge, are contained in: Fresno Irrigation District. Methods and devices used in the measurement and regulation of flow to service ditches, together with tables for field use. 39 p. Fresno Irrigation District, Fresno, California, 1928.

[24] See formulas 23, 24, and 25, page 85.

Here pressure varies from a minimum at the *vena contracta,* about half a pipe diameter below the orifice, to a maximum at about four and a half pipe diameters below the orifice. The most suitable place for the downstream pressure connection is at the *vena contracta,* where the differential head is a maximum and is not greatly affected by slight inaccuracies in location. When the lower pressure connection is in this position, the coefficient varies from about 0.59 to 0.61 for pipes of different sizes and for different ratios of orifice to pipe diameter. Because this coefficient is constant for a wide range of conditions, the thin-plate orifice is an

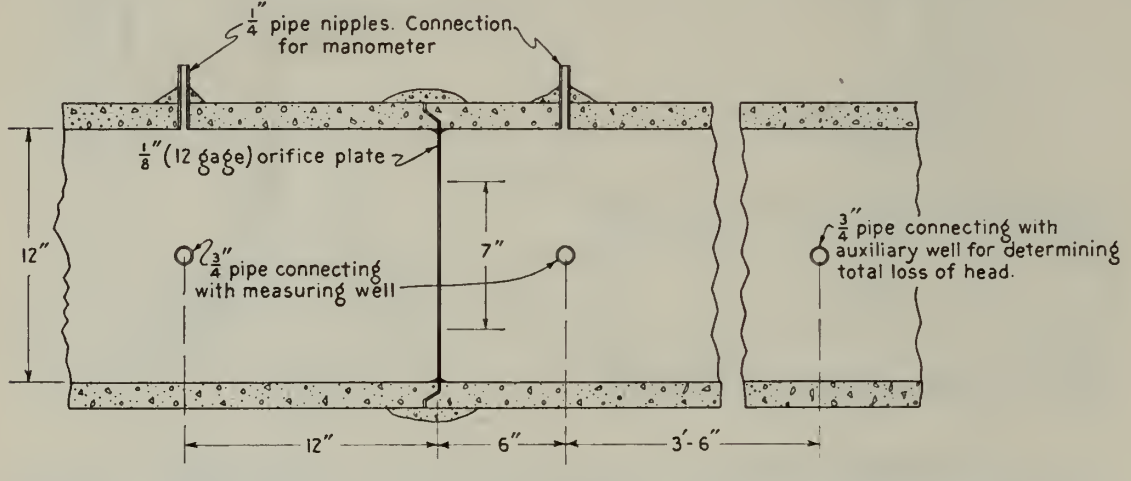


Fig. 38.—Longitudinal section of thin-plate orifice in concrete pipe line, as installed in outdoor hydraulic laboratory, Davis, California.

especially desirable water-measuring device. It has been used to only a limited extent, however, for measuring irrigation water.

The principal disadvantage of the thin-plate orifice as compared with the Venturi tube is the greater loss of head.

Calibrated Orifice for Measuring Pump Flow.—Some pump companies in California have used an orifice that screws on the end of the discharge pipe for measuring the flow from pumps. The arrangement is shown in figure 37. Since the orifice is free-flowing, the head is measured above the center of it. These orifices were calibrated by means of a weir, and tables and diagrams have been prepared for their use.

According to calculations from the flow diagrams, the coefficient varies from 0.60 to 0.66 for different orifices, although no consistent relations are apparent. In general, the smaller orifices have the higher coefficients. The inconsistencies probably result from calibration of the orifices at different times with different facilities.

Thin-Plate Orifice in Concrete Pipe.—The thin-plate orifice is well suited for measuring water in concrete pipe lines in the same manner as the Fresno flow meter is used. An orifice of this type was installed at Davis. Figure 38 shows a longitudinal section of this installation. A ⅛-inch (12-gage) plate 12½ inches in outside diameter, with a circular

orifice 7 inches in diameter, was set in the joint between two lengths of the concrete pipe. For determining the head, two methods were provided: an open measuring well and manometer-tube connections. The connections to the measuring well were made with ¾-inch pipes set flush with the inside of the concrete pipe on one side. In the top of the pipe, ¼-inch pipe nipples were cemented for manometer connections. These connections were one pipe diameter upstream and half a diameter downstream from the orifice. Another connection to an auxiliary measuring well was made 4 feet downstream from the orifice to determine the total loss of head. Tests on this installation gave a coefficient of approximately 0.60 and a total loss of head approximately 65 per cent of the differential head.

COLLINS FLOW GAGE

The Collins flow gage is used to measure the flow of water in pipe lines, especially from pumping plants. The device consists essentially of two parts: an impact tube (a special form of pitot tube) and a water-air manometer. The impact tube, a straight small-diameter brass tube inserted through the pipe, is divided by a partition at the center into two compartments, each containing a small orifice—an impact orifice on the upstream side and a trailing orifice on the downstream side. The differential head obtained is twice the velocity head. Hose connections are made from the ends of the tube to the manometer, the scale of which is so graduated that it indicates the velocity in the pipe directly in feet per second. Diagrams are furnished for converting to any desired unit of measurement for various pipe diameters.

For determining the flow through the pipe with this instrument, there are three methods. One is to place the orifice at the center of the pipe; approximately maximum velocity is thus secured, and a factor applied to obtain the average velocity. A second method, recommended by the manufacturer, is to obtain the velocities at two points, the average of which represents the mean velocity. A third method is to make a traverse on one or two diameters of the pipe, obtain the velocities at a number of points, and compute the flow for each of the several concentric rings somewhat as the flow of open streams is computed from current-meter readings.

COLOR-VELOCITY METHOD OF DETERMINING FLOW IN PIPE LINES[25]

This method consists of injecting a solution of coloring matter, usually fluorescein, potassium permanganate, or Kongo red, in the pipe and observing the time required for it to pass through a known distance.

[25] A discussion of this method appears in: Scobey, Fred C. Flow of water in wood-stave pipe. U. S. Dept. Agr. Dept. Bul. 376:1–88. Revised 1925.

Fluorescein is a red powder which, when dissolved in slightly alkaline water, even in very dilute solutions, is fluorescent, exhibiting a distinct greenish color by reflected light. As it varies greatly in strength, no directions for dilution are feasible. Only trial determines the required strength of a solution.

The procedure ordinarily followed in making discharge determinations by the color method is as follows: A small quantity of the fluorescein solution is injected in the water at the intake of the pipe line or at some point along the line by means of a "color gun." The time observations are made at the instant the coloring matter is introduced and at its first and last appearance at the second point of observation, usually at the outlet of the pipe. The mean velocity is determined from the average time required for the color to pass through the pipe; the discharge, from this velocity and the cross-sectional area of the pipe.

SALT-VELOCITY METHOD OF DETERMINING FLOW IN PIPE LINES

This method differs from the color method in that a salt solution, usually sodium chloride, common salt, which is a good electrical conductor, is injected into the pipe. This salt solution is detected at the second point of observation by means of an electric circuit consisting of two electrodes inserted in the water connected with a battery, a galvanometer, or an ammeter. A stronger current is indicated when the salt solution passes the electrodes, and the time required for the solution to traverse the pipe is determined as for the color method. An advantage of this method is that it does not necessitate seeing the water at the second point of observation. Salt-velocity and color methods are best adapted to experimental work in which the velocity is the desired element.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to all who aided in the preparation of this bulletin—especially to Professor Frank Adams for his direction and constant advice; to Professors O. W. Israelsen, H. B. Walker, and S. H. Beckett; and to Messrs. F. C. Scobey, George L. Swendsen, R. V. Meikle, and J. B. Brown.

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